

2012

Changes in Knee Valgus Angle of Female Athletes During Different Phases of the Menstrual Cycle

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CHANGES IN KNEE VALGUS ANGLE OF FEMALE ATHLETES DURING
DIFFERENT PHASES OF THE MENSTRUAL CYCLE

By

Eric John Daniels

THESIS

Submitted to
Northern Michigan University
In partial fulfillment of the requirements
For the degree of

MASTER OF SCIENCE EXERCISE SCIENCE

Graduate Studies Office

2012

SIGNATURE APPROVAL FORM

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ABSTRACT

CHANGES IN KNEE VALGUS ANGLE OF FEMALE ATHLETES DURING DIFFERENT PHASES OF THE MENSTRUAL CYCLE

By

Eric John Daniels

Background: Seventy percent of ACL injuries occur in athletics while changing direction. Previous research reported increased anterior translation (ACL laxity) between menstrual cycle phases, which is believed to increase ACL injury risk. Females demonstrate increased values of knee valgus, an ACL injury risk factor, during change of direction. It is unknown why this occurs, but menstrual cycle phases are believed to influence knee kinematics. Since knee valgus is a predictor of ACL injuries, it is important to study if valgus angles change during the menstrual cycle. The purpose of this study was to determine if knee valgus angles change during four menstrual cycle phases.

Hypothesis: Menstrual cycle phase affects the amount of knee valgus during a drop jump.

Methods: Ten healthy, college-aged women who met inclusion criteria were tested through one menstrual cycle. Subjects completed four testing sessions during menses, mid-follicular, ovulation, and mid-luteal phases. Testing times were calculated using Eiling and colleagues (2007) protocol. Each session consisted of marker attachment to the subjects' left hip, knee, and ankle before completing three-drop jumps from 30 cm. Video was recorded at 300 fps using a high-speed camera and was imported to a computer for digitizing and analysis.

Results: No significant difference in knee valgus was found between menstrual cycle phases.

Conclusions: Knee valgus is a risk factor for ACL injury, however valgus angle changes were not found between menstrual cycle phases. This study contrasts previous research, which reported changes in anterior knee motion during the menstrual cycle.

Key Words: Knee ACL, Video Analysis, 2-Dimensional, Drop Jump

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DEDICATION

This thesis is dedicated to my parents John and Lisa Daniels without your guidance and continued support I would have never completed this project, and to my fiancé, Alyson Ancil who has shared my frustrations and struggles since I began.

ACKNOWLEDGMENTS

The author would like to thank the members of his thesis committee, Dr. Randall Jensen, Ph.D, FACSM, FISBS, CSCS, Dr. Marguerite Moore, Ph.D, AT, ATC, and Dr. J. Bryan Dixon, MD without their assistance and support this project could not have been completed. He would also like to thank the Maine Athletic Trainers' Association and Colby Lash, MS, AT, ATC, PES for their assistance throughout this project.

This thesis follows the format prescribed by the Journal of Athletic Training.

PREFACE

The cost of the research covered in this project has been underwritten by grants from the Maine Athletic Trainers' Association, Maine, and Northern Michigan University, Marquette, MI. Equipment used for this research project was borrowed from the Northern Michigan University's Health, Physical Education and Recreation department.

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CHAPTER ONE: MANUSCRIPT SUBMISSION

INTRODUCTION

The effect of sex hormones on the female body is believed to alter the strength of the anterior cruciate ligament (ACL) and its risk of injury during different phases of the menstrual cycle.¹⁻¹⁰ Many studies have investigated and reported ACL injury risk factors,^{1,2,3,4,6,7,10-29} however two factors that require further research are hormone fluctuations during the menstrual cycle and valgus angle of the knee during change of direction activities.

Anterior cruciate ligament (ACL) injuries are becoming a problem of epidemic proportion within the world of female athletics. Female athletes are at a two to ten times greater chance of tearing an ACL than their male counterparts while participating in athletics.^{1,3,5,11,12,13} Since the implementation of Title IX in the 1970's there has been an exponential increase of female participation in athletics at all levels of participation thus resulting in an increased number of female injuries.^{11,14} ACL injuries continue to be one of the most common orthopedic injuries treated by sports medicine specialists.¹⁵ Estimations of ACL reconstructions have risen from 50,000 in 1982, to more than 250,000 in 2006.^{2,16} Annually, female athletes in the United States experience 100,000 to 250,000 ACL injuries, which results in over \$650 million spent annually on high school and collegiate varsity athletics alone.³⁰ A significant number of the patients who have an ACL reconstruction surgery will usually present with life-long struggles such as meniscal lesions, osteoarthritis, improper knee function, and arthrofibrosis.^{17,30,31} It is estimated

that of the females who undergo an ACL reconstruction 50% to 100% of them will develop pain and noticeable osteoarthritis within 12 to 20 years after their surgery.³⁰

Many theories, or risk factors, exist as to why ACL injuries occur more in females than males. Previously investigated risk factors include increased Q angle, foot pronation, body composition, geometric size of the ACL, and sex-hormone fluctuations.^{1,2,3,4,6,7,10-29} Several studies report that increases in ACL laxity due to fluctuations of sex hormones occur during different phases of the menstrual cycle.^{1,3,4,5,6,9,10} Many variables increase the risk of ACL injury for females and if researchers are able to determine why female athletes incur these injuries, significant decreases in financial and emotional losses may occur.

The menstrual cycle is a cyclic process that occurs as a result of fluctuating female sex hormones (i.e. estrogen, progesterone, luteinizing hormone, and follicular stimulating hormone) for the reproductive process.³² Researchers have located hormone receptors in the ACL that have been theorized to cause a change in ACL strength during different phases of the menstrual cycle.^{1-10,33} The known changes to ACL strength during the menstrual cycle, coupled with high risk movements (knee valgus) may be a reason for such a high incidence of female injuries when compared to males.

The high rates of ACL injury in female athletics increases the need for further research to help identify and lower injury risk factors. There have been equivocal research results with regard to the effect of the menstrual cycle on ACL injury risk in female athletes.^{1,3,4,5,6,9,10,34,35,36} The majority of research available has investigated ACL laxity (anterior translation) in a static testing scenario while utilizing knee arthrometers.^{1,3,4,5,6,9,10} This type of testing allows researchers to determine if laxity alone

occurs without the influence of other knee stabilizers. It is logical that testing should be completed during dynamic movements to identify if similar changes in knee kinematics occur to what was previously reported during active movements.^{1,3,4,5,6,9,10} To date research is not available that uses video analysis techniques to determine if knee valgus angles change at different phases of the menstrual cycle during a drop jump movement.

The purpose of this study was to determine if significant changes in knee valgus angle occur during four different points of a subject's menstrual cycle, while completing a drop jump task. Researchers hypothesized that the valgus angle of the female knee will vary significantly at different phases of the menstrual cycle during a drop jump movement.

METHODS

Subjects

Ten female subjects were recruited from a pool of volunteers for this study. Subject recruitment was completed by contacting players on the varsity soccer and volleyball teams as well as recreational athletes from within the Northern Michigan University community.

Inclusion criteria required that the subject be a female between the ages of 18-24, without orthopedic lower limb or known cardiovascular pathology, and without contraindications to exercise. Selected subjects had no history of knee injury within the last six months, no previous ACL injury on the tested extremity (left leg), no history of pregnancy, eumenorrhea for the previous three months and during the study, and regular athletic participation at least three times per week (recreational or team).

Prior to data collection participants completed an informed consent (Appendix A), a medical history questionnaire (Appendix B), a menstrual history recall (Appendix C), and a PAR-Q. Northern Michigan University's Institutional Review Board approved this study (approval number HS-11-391). This paperwork was completed to verify that each subject met inclusion criteria and was volunteering for the study.

Procedures

The protocol used by Eiling and colleagues³ was utilized to determine the appropriate days of testing for each subject. Each of the participants completed four separate testing sessions, which consisted of three trials per session. Each session aligned with a phase of the menstrual cycle: day one of menses, mid-follicular, estimated day of ovulation, and mid-luteal. The researchers determined, from menstrual cycle recalls, the estimated beginning day of the subject's menstrual cycle, starting with the first day of menses. From that day, counting back 14 days provided an estimated day of ovulation. Counting back seven days from the estimated onset of menses provided the mid-luteal phase testing day, and by finding the median day between the current cycle's first day of menses and estimated day of ovulation the mid-follicular testing day was determined. All testing sessions were completed on the calculated dates.

All athletes wore spandex pants/shorts, and low top tennis shoes. Prior to testing, each subject was fitted with markers. The markers were placed on the anterior aspect of the subject's legs at landmarks assessed during kinematic analysis. The first marker was located four inches directly inferior to the anterior superior iliac spine. The second one was placed at the center of the patella on the joint line. The third was placed three inches

superior to the talocrural joint. All markers were placed on the subject's left leg while standing.

The camera used for video captures was a digital camera (Casio model EX-F1) capable of recording high-speed video at 300 frames per second. The camera was set up two meters away from the location that each participant performed the drop jump. It was positioned so a frontal view of the subject's movement could be recorded. Camera location allowed for a viewing area large enough to witness the participant's body from the navel down to perform the drop jump. The video was then converted to an .AVI format utilizing a Pazera Free .MOV to .AVI converter.³⁷ The video was imported into MaxTraq 2D³⁸, which allowed researchers to analyze knee valgus angle. The markers placed on each subject allowed for identification and measurement of knee valgus angle during the athlete's movements. Only valgus angles were analyzed during this study.

Subjects were asked to arrive for a 20-minute session on four separate occasions. At the start of each session, the subject was asked if there had been any change to her menstrual cycle; no changes were reported. The subject then completed five minutes of warm-up on a cycle ergometer. Upon completion of cycle ergometer usage, she was fitted with markers for kinematic analysis. Once fitted appropriately, she performed three-drop jump trials from a height of 30 cm. This movement required her to step off a box, land on both feet, and jump as high as possible in a vertical plane. After she completed the three trials, the markers were removed and she was done with that testing session. Prior to leaving, a reminder of the next testing session was provided. Reminder emails were sent out a day or two before each testing session to help reduce the incidence of missed sessions. No subjects missed their scheduled visit.

Once each testing session was completed, each video was truncated to eliminate unwanted footage and each segment was digitized per the recommendation of the MaxTraq 2D software.³⁸ Digitizing of the videos enabled the identification of knee valgus angles from the subjects' movement (see Figure 1). The trial that exhibited the greatest amount of knee valgus angle during the first landing when changing from eccentric to concentric contraction was utilized as the measurement for statistical analysis from each session.

Insert Figure 1 Here

Version 18.0 of Statistical Package for the Social Sciences was used to complete the statistical analysis.³⁹ Collected peak valgus angle measurements, at contact, were analyzed through a General Linear Model Repeated Measures ANOVA. This test was completed to determine if significant differences exist between knee angles at the four different menstrual cycle phases³⁹

RESULTS

No significant differences were found to exist between knee valgus angles during the four menstrual cycle phases [$F(2,20) = .699, p > .05$]. Figure 2 illustrates the mean valgus angle, and standard deviations, experienced at each phase of the menstrual cycle for the subjects.

Insert Figure 2 Here

DISCUSSION

The purpose of this study was to investigate if knee valgus angles varied during different phases of the menstrual cycle. The current study used a self-reported menstrual cycle history to calculate four appropriate times of testing for one complete menstrual

cycle of each subject; menses, mid-follicular, ovulation, and mid-luteal.³ Video analysis in the frontal plane was used to analyze the amount of valgus motion exhibited during a drop jump movement. The researchers hypothesized that a change in knee valgus angle would occur between different phases of the menstrual cycle. More specifically, that change would occur when estrogen levels are expected to be the highest during the mid-follicular phase of the menstrual cycle, just before ovulation.^{1,6,15,29,32,40}

The current findings led researchers to believe that changes in hormone levels during the four tested menstrual cycle phases do not contribute to the amount of knee valgus experienced. Although the current study did not analyze hormone levels, a previous study did analyze and identify hormone level changes during each of the four phases tested for the current study.⁶ More specifically, these results demonstrate that the increased valgus angle females exhibit does not appear to be influenced by hormonal fluctuations as previously indicated for anterior translation^{1,3,4,5,6,8,9}, which led the current researchers to believe that the increased risk is due to other factors.

This is the first study known to the authors that investigates if knee valgus angle varies between four different phases of the menstrual cycle, while using a drop jump movement and video analysis to determine knee valgus angle. In contrast to previous studies that have reported anterior knee laxity^{1,3,4,5,6,9,10}, the current study did not find changes in valgus motion during the four different phases. These findings are supported, however, by four similar studies that reported no significant change in anterior knee joint laxity throughout a subjects' menstrual cycle.^{3,34,35,36}

Conflicting research regarding the menstrual cycle's effect on knee laxity creates a sense of uncertainty for the authors, especially since the current study investigated

changes in valgus motion and other researchers analyzed anterior motion. Although, the two movements are different, it seems logical to theorize that anterior and valgus motions would be influenced similarly at different phases of the menstrual cycle. However the medial collateral ligament may not be affected by female sex hormones similar to the ACL^{1,4,5,6,9,10}, which may be a logical reason explaining why no differences were found in the current study. This increases the importance of investigating valgus movements at the knee because it has been identified as an ACL injury risk factor.^{1,3,4,5,6,8,9}

The study by Eiling and colleagues³ served as a foundation for the current study. A similar protocol was utilized to determine time of data collection, with the exception that the current study did not utilize hormone analysis to verify menstrual cycle phase. The results of Eiling and coworkers³ demonstrated that no significant change in anterior knee laxity occurred between any of the four testing sessions. They did however report percentage increases between the phases. Most noticeably between the phases was an increase in laxity of 10% from mid-follicular phase to ovulation. This increase in laxity then decreased by 10% from ovulation to mid-luteal.³ As their study was critical in the development of the current one, it is important to note their results. Statistically it is reasonable to report that each study, Eiling and colleagues³ and the current one, exhibited similar results, which indicate no significant changes between four distinct phases of the menstrual cycle.

The use of hormone analysis to determine menstrual cycle phases raises a question about concentrations of hormones that subject's exhibit. Each person is different which will result in differing concentrations of hormones to be present. If subjects are not tested daily with hormone analysis then results may miss the "important"

concentrations levels. This leads one to question if a threshold exists that requires a certain amount of hormone to be present for it to influence knee kinematics.

Three other studies, which report no significant changes in knee laxity, have results that are similar to the current study's.^{34,35,36} Two of the studies completed three testing sessions during the follicular, ovulatory, and luteal phases while the third study analyzed five different time points.^{34,35,36} Each study evaluated hormone levels using blood draws, which allowed for accurate calculations of the subjects menstrual cycle.^{34,35,36} Although the current study utilized a different protocol than the three above mentioned investigations, similar results were reported by all. The current study demonstrated no change in knee valgus at different points through the menstrual cycle, which was completed without the use of hormone analysis. If researchers that do not perform hormone analysis, but instead use self-reported menstrual cycles, are able to extrapolate similar results as those who use hormone analysis, then it may eliminate the need for future research to incorporate hormone analysis. This is important to note because hormone analysis may not be easily accessible for all researchers due to time or financial restrictions.

The use of two-dimensional (2D) video analysis has been reported to accurately measure the magnitude of knee valgus angle with a frontal view.⁴¹ The validity of 2D analysis is important because of the costly equipment and large amounts of time required for three-dimensional data acquisition.⁴¹ Three-dimensional analysis limits the ability to test large groups of individuals similar to 2D analyses because of the increased time requirement for set up, calibration, and take down, as well as the large financial expense.⁴¹ However, 2D video analysis is unable to calculate the amount of tibial

rotation that occurs during knee movement.⁴¹ The tibial rotation contributes to the amount of knee valgus angle experienced; thus without rotation's effect being investigated in the present study, decreased accuracy of valgus measurements may be present.⁴¹

The statistical analysis revealed large standard deviations between the subjects during each phase of the menstrual cycle. The increased size of these standard deviations decreases the likelihood of results being significantly different. However, the use of Repeated Measures analysis would minimize the inter-individual variability by comparing each subject to herself.

When subjects asked for feedback on their jumping technique, none was given. No feedback was provided because the researchers did not want to influence a subject's subsequent trials. If feedback was given to one subject, then to eliminate its potential affect, feedback should be given to all subjects. Instead, subjects were asked to maintain consistency of their jumps. Although the subjects attempted to complete identical trials in each session, the reality is that this is nearly impossible. In some instances, subjects demonstrated full body rotation towards one side, which influenced the frontal view image. In other cases, subjects appeared to land with one foot closer to the camera than the other one, which can also alter the frontal image. The differences in landing form may have affected the measurements resulting in the larger standard deviations found. Although these factors may influence the movements, McLean et al.⁴¹ previously reported no difference between two-dimensional and three-dimensional video analysis during running, jumping, and cutting motions. Sagittal views of the subjects' jumps would help control for rotation that occurred. The sagittal and frontal views could be

interlaced, creating a modified three-dimensional image, which would help reduce the effect of rotation experienced.

The current study did not evaluate if specific hormone concentrations affect valgus motion or if individual hormones correlate with valgus movements. Additional research needs to be completed to verify the current study's results. Future researchers should utilize similar menstrual cycle phases for analysis and are encouraged to complete hormone analysis, through blood samples, to more accurately determine menstrual cycle phases. Researchers should also incorporate more testing sessions per phase, which may result in a better understanding of individual hormonal influence on valgus motion. The use of three-dimensional analysis is encouraged, as it will allow for increased accuracy of knee kinematics. Future researchers are also encouraged to evaluate consecutive menstrual cycles to help demonstrate reliability of hormone fluctuations and changes in knee motion.

CONCLUSION

The current study examined if different phases of the menstrual cycle influenced the amount of knee valgus motion during a drop jump movement in ten female subjects. It was determined that no significant changes in valgus angle occur during the four different phases of the menstrual cycle. This does not negate the fact that female athletes experience two-to-ten times more ACL injuries than males^{1,3,5,11,12,13}, which the authors believe to be a result of differing joint biomechanics. As the increased risk of ACL injuries continues to plague female athletes, it is important for researchers to continue with studies of this nature, working towards an end goal of reducing the female risk of non-contact knee injury.

FIGURES



Figure 1. Measurement of valgus angle at landing.

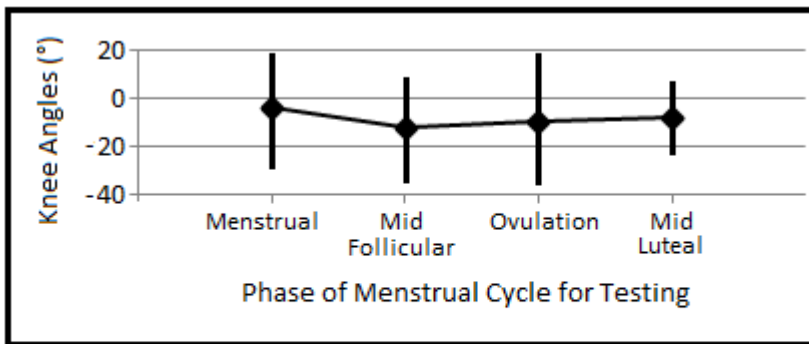


Figure 2. Mean valgus angle measurements for subjects at the four different phases of the menstrual cycle with standard deviations demonstrated. 0° represents no valgus motion, - values represent valgus motion, + values represent varus motion.

CHAPTER TWO: LITERATURE REVIEW

Knee valgus angles have been found to be a risk factor in female ACL injuries.^{8,11,15,16,20,30,42} If differences in knee valgus angles can be established during different phases of an athlete's menstrual cycle then guidelines for activity can be created, which may help reduce the risk of ACL injuries.

To gain a more comprehensive knowledge from research conducted on the reasons behind a female's increased risk of ACL injury, this review of literature is divided into seven major sections: (a) the anterior cruciate ligament; (b) anterior cruciate ligament injury; (c) predisposing risk-factors in females; (d) the menstrual cycle; (e) anterior cruciate ligament laxity; (f) neuromuscular stiffness; and (g) video analysis.

ANTERIOR CRUCIATE LIGAMENT

The anterior cruciate ligament (ACL) is one of four major ligaments that provide stability to the knee.^{1,7} It works in conjunction with the posterior cruciate ligament (PCL), medial collateral ligament (MCL), lateral collateral ligament (LCL) and other structures to help provide necessary stability at the knee.⁷ It originates at the intercondylar eminence of the tibia and runs posterior, lateral, and superior where it attaches to the posterior medial aspect of the lateral femoral epicondyle.^{1,7} It functions to limit forward translation and rotation of the tibia on the femur.^{7,34} If one of these structures, especially the ACL, is injured the athlete has a significantly decreased amount of knee stability.¹ The ACL experiences force at all aspects of knee motion but experiences the most between full extension and approximately 20° of flexion.³ When the knee is in either of these two positions and is coupled with a sudden internal rotation

of the tibia, adduction of the hip, or valgus positioning of the knee, they combine to be some of the most common mechanisms for a non-contact ACL injury.^{3,13,31}

After an ACL tear, surgical intervention is usually required for an athlete to remain competitive. However, some athletes are able to maintain an active lifestyle while ACL deficient. This can be achieved using a brace for added stability and/or rehabilitation.

ANTERIOR CRUCIATE LIGAMENT INJURY

More than 70% of all ACL injuries occur in athletic participation during movements of deceleration, eccentric contraction, and sudden change of direction.^{3,16,17} Eighty percent of ACL injuries occur in a noncontact situation where the athlete is rapidly decelerating and changing direction with their foot planted firmly to the ground.³ The athlete usually complains of a “buckling” feeling that occurs during an ACL injury.⁷ It is often accompanied by a loud pop and immediate pain.⁷

Olsen et al.¹² found that two situations resulted in an ACL injury for European female handball players: either a plant-and-cut movement or a single leg landing.¹² Both situations consisted of the athlete’s foot being firmly planted on the ground, the knee in almost full extension, rotation of the tibia, and a valgus collapse.¹²

In 2009, Boden and colleagues reported that as male and female athletes decelerate or change direction there is an increased amount of knee valgus that occurs between initial contact and subsequent views.⁸ Through video analysis, females demonstrated significantly greater amount of knee valgus angle when compared to matched male subjects.⁸ It is not clear, why this increased knee valgus occurs but some believe that females exhibit increased joint laxity due to hormonal fluctuations.^{1,3,4,5,6,8,9}

There is sufficient evidence through scientific research to conclude that female athletes are at a greater risk of experiencing an ACL injury than male athletes.^{1-6,8,9} Much of the research demonstrates that females experience an increased amount of valgus collapse during landing movements, which is one of the identified risk factors for ACL injuries.^{8,11,15,16,20,30,42} Krosshaug et al.²⁰ determined that female athletes have a 5.3 times greater risk of valgus collapse than male athletes, which was deemed an ACL injury risk factor. They also found that female athletes who incurred ACL injuries experienced greater hip and knee flexion angles when compared to men at initial contact and time of injury.²⁰ Hewett et al.¹¹ prescreened 205 female subjects for lower body kinematic control during a jump-landing task using a three-dimensional video analysis program. Of the 205 athletes, nine received ACL injuries while participating in their respective sports.¹¹ Those subjects who received an ACL injury experienced 8.4° more of knee valgus at initial contact and 7.6° more at maximum contact when compared to those who were injury free.¹¹

It is important to understand how the ACL is injured during activity so steps can be taken to help prevent the injury from occurring.¹³ Many factors are believed to increase the risk of ACL injury for female athletes.² These factors include increased quadriceps (Q)-angle, foot pronation, and smaller ACL geometric measurements.²

PREDISPOSING RISK-FACTORS IN FEMALES

Quadriceps Angle

According to Insall and colleagues⁴³, the Q-angle is defined as the line of pull of the quadriceps muscle and the patellar ligament, as measured by drawing a line from the anterior superior iliac spine to the center of the patella and a second line from the center

of the patella to the center of the tibial tubercle. It was determined that women have a larger hip width to femoral length ratio, when compared to men, which results in an increased Q angle.⁴³

Hall and Horton²¹ studied 50 men and 50 women to compare Q angle measurements. They found that women had a significantly greater Q angle than men with a mean increase in angle of 4.6°.²¹ Griffin² reported the increased angle amplifies the amount of force experienced on the ACL by increasing pressure to the lateral aspect of the knee, resulting in an increased knee valgus angle. He also found that athletes who sustained knee injuries had significantly greater Q angle values than those who did not.² Shambaugh and colleagues¹⁸ were able to quantify this when they found that of 45 athletes studied, the mean Q angle for injured athletes was 14° and those who were not injured was 10°.

Foot Pronation

Foot pronation is a combination of subtalar eversion, foot abduction, and ankle dorsiflexion.¹⁴ Increased foot pronation is believed to be a risk factor for ACL injury because it increases the amount of internal tibial rotation.^{2,14} As tibial rotation occurs, the ACL tightens increasing the likelihood that it may become injured.¹⁴ In 2000, Allen and Glasoe²² reported that subjects who received an ACL injury had a significantly greater navicular drop when compared to uninjured, matched subjects. The navicular drop test is used to help assess the amount of foot pronation one experiences.^{22,23}

Foot pronation in women does not differ significantly from men. However, when the interaction between foot pronation, anterior pelvic tilt, genu recurvatum, and knee laxity was evaluated, foot pronation was found to significantly increase the likelihood of

injury in females.²⁴ This is important to note because despite the lack of significant difference between men and women for foot pronation, its impact on female ACL injuries is critical. Another topic that is believed to increase ACL injury is a persons' body composition.^{19,26}

Body Composition

Body mass index (BMI) is a scale used to predict the health of a person using a height to weight ratio.¹⁹ Classifications of BMI include underweight, normal, overweight, and obese.¹⁹ In 2003, Uhorchak and colleagues²⁵ determined that female cadets who had a BMI 1 standard deviation or more above the average were at a 3.5 times greater risk of ACL injury than those with a lower BMI.

It was reported in 2001 by Anderson and colleagues²⁶ that females exhibited increased body fat percentages when compared to matched male subjects. Even after subjects' data was adjusted for body weight, the male subjects were able to produce greater peak torques, work, and power than the female subjects.²⁶ Thus, females exhibit less lean body mass and more body fat mass decreasing their ability to resist force production and maintain proper kinematic control.²⁶ This is believed to increase the female athlete's risk of ACL injury.²⁶ Although, few studies have investigated the relationship between body composition and ACL injury, those that have report findings which support the notion that female body composition influences ACL injury rates.^{2,25,26}

ACL Size

An uncontrollable variable that is believed to increase the risk of female ACL injury is the geometric size of the ACL. It is hypothesized that the forces absorbed by the ACL are proportional to body size.^{2,15} A logical thought is that a larger person has a

larger ACL, which allows them to withstand greater forces compared to a smaller person with a smaller ACL. However, it was determined that when matched males and females were compared for ACL size, the female ACL was smaller.^{2,26} Even after subjects were adjusted for body weight the females presented with a significantly smaller ACL.

A cadaveric study by Chandrashekar, Slauterbeck, and Hashemi²⁷, reported that female ACL's were shorter, had less cross-sectional area, less volume, and less mass when compared to their matched male subjects. The researchers believed that this difference in ACL size is a major contributing factor to the significant increase of female ACL injuries when compared to males.²⁷ These studies increase the knowledge base available to healthcare professionals and support the belief that female anterior cruciate ligaments may be at an increased risk of injury because of their size.^{2,15,26,27} If female athletes demonstrate smaller ACL's when compared to males the combination of this and the menstrual cycle may be the cause of increased injury rates.

MENSTRUAL CYCLE

The onset of puberty for a young female is marked with the beginning of her menstrual cycle.³² The source of the menstrual cycle lies within the endocrine system between the hypothalamus, pituitary gland, and ovaries.³² The menstrual cycle occurs due to numerous hormonal reactions that result in cyclic biochemical changes, usually lasting an average of 28-30 days.^{1,32} Many hormones contribute to the menstrual cycle's regular occurrence and below is a general overview and explanation of the menstrual cycle.

Due to the greater ratio of female ACL injuries to male ACL injuries the menstrual cycle has become a major topic of discussion among risk factors for female

ACL injuries. Multiple phases make up the menstrual cycle: the menstrual phase (approximately days 1-5), follicular phase (approximately days 6-12), ovulation (days 13-15) and the luteal phase (approximately days 16-28).^{6,44} The menstrual phase is the result of a large decrease in the concentration of estrogen and progesterone and begins at the onset of menses.⁶ The follicular phase begins when an increase in estrogen and luteinizing hormone coupled with a decrease in follicle-stimulating hormone takes place.³² Ovulation occurs when a sudden drop in estrogen, a surge in luteinizing hormone, and a constant rise in progesterone occurs.³² The luteal phase is next and is the time between ovulation and onset of the next menses.³² It is during this phase that the corpus luteum increases estrogen, progesterone, and relaxin secretions for the remainder of the cycle.^{6,32} Both estrogen and progesterone maintain low concentrations during menstruation and a high concentration during the luteal phase.⁴ If fertilization and implantation do not occur then estrogen and progesterone will drop and the cycle begins again.^{6,32}

Available research demonstrates a greater risk of receiving a non-contact ACL injury during the days preceding the ovulation in the menstrual cycle, more specifically an increased risk between days 9-14 of a typical 28-day cycle.^{4,5,15,28} It is not fully understood why this occurs, but some speculation says that it is due to the fluctuation of progesterone and estrogen during the cycle and the effects that each of these hormones have on the ACL.^{1,15,6,29} Human connective tissue in the knee has been found to house receptors for female sex hormones. More specifically hormone receptors for estrogen, progesterone and relaxin have been found in the ACL of female subjects but not male subjects^{33,45}. These hormones have a large effect on a woman's body throughout a

menstrual cycle and pregnancy. The relaxin's ability to allow parturition to occur clearly highlights its effect on connective tissue at other parts of the body. It is logical to conclude that relaxin may potentially increase the amount of laxity found in the ACL through different phases of the menstrual cycle.

ANTERIOR CRUCIATE LIGAMENT LAXITY

The conflicting research of ACL laxity and its relationship to hormonal fluctuations has become very controversial.^{1,3-10,34,35,36} The following will briefly outline research that demonstrated significant changes in ACL laxity as well those that did not find any changes. No research was found that showed decreases in ACL laxity, the research only reported no difference.

The connection between non-contact ACL injury rates for female athletes and the menstrual cycle was investigated in the mid-1990's by Wojtys et al.¹ They completed a study that involved 28 female athletes who received a non-contact ACL injury within three months of the study. The subjects were asked to complete a questionnaire asking for date of injury, mechanism of injury, if injury occurred during practice or game, and how the injury occurred (e.g. from planting of foot, landing, jumping, or other physical movement).¹ The researchers also asked for a detailed menstrual history that covered dates, irregularities, length, premenstrual symptoms, and oral contraceptives used.¹ This data was analyzed using a Pearson chi-square test to calculate the frequencies of injury during different phases of a woman's menstrual cycle.¹ The data showed a significant variation in ACL injuries during different phases.¹ More specifically, a larger percentage of injuries occurred during ovulation where injury rates were much higher at 29% than predicted at 18%.¹ Fewer injuries were observed during the follicular phase at 13 % than

what was expected at 32%.¹ No definitive reasoning for the difference in injury rates has been determined, but the following studies attempted to reason that it is likely due to changes in ligament laxity through the menstrual cycle.^{1,4,5,6,9,10}

One of the first studies found that investigated changes in knee laxity during the menstrual cycle was by Heitz and colleagues.⁶ Researchers investigated ACL laxity during a normal 28-30 day menstrual cycle.⁶ Estrogen and progesterone levels were measured in seven female subjects on the first day of menses and ACL laxity was measured using a KT-2000 knee arthrometer.⁶ Subjects returned eight separate times during their menstrual cycle, on days 10, 11, 12, 13, 20, 21, 22, and 23 to have a blood samples taken which allowed the researchers to determine the participant's estrogen and progesterone levels during follicular and luteal phases.⁶ The authors showed a significant difference between high and low concentration levels of estrogen and progesterone and ACL laxity during different phases of the menstrual cycle.⁶ This demonstrated that higher levels of estrogen and progesterone resulted in an increased laxity of female anterior cruciate ligaments.⁶ Researchers discovered that a greater amount of ACL laxity was present in female participants during the luteal phase of the menstrual cycle.⁶

A similar study by Deie et al.⁴ determined that there is a positive correlation between ACL laxity and different phases of the menstrual cycle. A study of 16 women was completed that identified changes in ACL laxity during different phases of the menstrual cycle.⁴ This study used changes in basal body temperature and serum concentrations to determine which phase the subject was in.⁴ Basal body temperatures were used to determine time of ovulation because a female's basal body temperature will rise slightly a prior to ovulation.⁴ Knee laxity measurements were completed using a KT-

2000 knee arthrometer.⁴ Researchers report finding a significant difference in the anterior displacement of the knee at 89 N between the follicular and ovulatory, and follicular and luteal phases.⁴ They also discovered a significant difference between follicular and luteal phases at 134 N of force.⁴ These findings suggest that female sex hormones effect anterior displacement of the knee during different phases of the menstrual cycle.⁴

After changes in ligament laxity were reported in 2002⁴, Shultz et al.⁹ investigated which hormones affect knee laxity. They studied 22 non-athletic female participants to determine what effect estrogen, progesterone, and testosterone have on knee laxity. Specifically they wanted to investigate if individual or combinations of hormones explained greater variance in knee laxity.⁹ Each subject was followed through one complete menstrual cycle where blood samples and knee laxity measures were collected daily.⁹ Blood samples were analyzed for estradiol, progesterone, and testosterone.⁹ Anterior knee laxity measurements were collected utilizing a KT-2000 knee arthrometer with parameters of 25° of knee flexion at 133 N of force.⁹ Researchers discovered that the interaction of estradiol, progesterone, and testosterone explained the greatest amount of variance for knee laxity measurements.⁹ The main effects of each hormone explained significant amounts of variance but more variance was explained when combinations of the hormones were evaluated.⁹ This study continues to support the findings that a relationship exists between female anterior knee laxity and hormone fluctuations throughout the menstrual cycle.⁹

Another study reported increased knee laxity in 2009, when twenty-six college aged female subjects were recruited to investigate if changes to anterior knee laxity

occurs during different phases of the menstrual cycle.⁵ Data was collected at three different times of the cycle; follicular – estrogen and progesterone are low, ovulation – estrogen surge, and luteal – peak progesterone.⁵ A KT-2000 arthrometer was used for anterior laxity testing.⁵ A significantly greater amount of laxity was found during ovulation (high estrogen) then during luteal (low estrogen and high progesterone).⁵ Maximum laxity during ovulation (high estrogen) was significantly higher than during the follicular phase (low estrogen and progesterone).⁵

A study conducted by Eiling and colleagues³ tried to identify a correlation between hormonal fluctuations and increased laxity of muscles and ligaments during different phases of the menstrual cycle. A group of 11 teenage netball players were chosen for the study.³ Tests were conducted to determine ACL laxity via a KT-2000 knee arthrometer and hormone concentrations via blood samples.³ These tests were completed four times throughout each of the participants' menstrual cycle: first day of menstruation, mid-follicular phase, day of ovulation, and mid-luteal phase.³ Different statistical analyses were completed; a One-way ANOVA was completed to compare knee laxity between the four stages of the menstrual cycle.³ The repeated measures ANOVA did not reveal any significant effect; however, increased knee laxity was observed during the study.³ An average increase of 3.9% was observed from onset of menstruation to mid-follicular phase, at ovulation, a 10% increase in laxity was observed when compared to mid-follicular measurements, and after ovulation, a decrease in anterior laxity of 10% was observed.³ Large standard deviations existed, which resulted in large percentage changes without significance. These results did not show a significant effect of the

menstrual cycle on anterior knee laxity; however, they go to show that changes do occur to ACL laxity.³

In 2003, Romani and colleagues¹⁰ reported their research, which analyzed correlations between estradiol, estrone, estriol, progesterone, and sex hormone-binding globulin to ACL (anterior knee translation) stiffness. Blood analysis was completed for hormone levels and laxity measurements were completed using a KT-2000 arthrometer.¹⁰ Data was collected during the subjects' menses, ovulation, and luteal phase.¹⁰ Researchers determined that estradiol was negatively correlated to ACL stiffness at all phases but it grew in strength near ovulation, meaning that as estradiol increased ACL stiffness decreased or became more lax.¹⁰ Estradiol and estrone were found to have a significant difference in knee laxity between menses and near ovulation and the luteal phase.¹⁰ Researchers also found higher concentrations of sex hormone binding globulin during increased knee laxity between the ovulation and luteal phases.¹⁰ This research investigated multiple components of estrogen (i.e. estradiol, estrone, and estriol) and their affect on laxity.¹⁰

Studies that did not determine significant changes in knee laxity also exist.^{3,34,35,36} Van Lunen et al.³⁴ studied twelve female subjects to see if a difference could be found in knee laxity between menstrual cycle phases. Three testing sessions were completed where each subject had a blood draw completed and anterior laxity was measured using a KT-2000 arthrometer and x-ray.³⁴ It was determined that no significant differences were found between follicular, near-ovulation, and mid-luteal phases of the menstrual cycle.³⁴

A similar study by Hertel and associates³⁵ also investigated the effects of female sex hormones on knee laxity. Fourteen college aged female subjects were recruited and

tested at three different phases of the menstrual cycle: mid-follicular, ovulation, and mid-luteal.³⁵ All subjects experienced regular menstrual cycles, had confirmed ovulation, and were members of a competitive soccer or cheerleading team.³⁵ Urine analysis was completed daily through one complete menstrual cycle to determine concentrations of estrone-3-glucuronide and pregnanediol-3-glucuronide.³⁵ These hormones have been found to correlate with estrogen and progesterone fluctuations.³⁵ Researchers used a KT-1000 knee arthrometer to determine knee laxity at 133 N of force.³⁵ Highest levels of estrone-3-glucuronide were found during ovulation and pregnanediol-3-glucuronide during the mid-luteal phase.³⁵ They reported that no significant changes in knee joint laxity were found between any points of the menstrual cycle.³⁵

A study consisting of 17 males and 17 females investigated if increased levels of serum estradiol and progesterone were associated with increased knee and ankle laxity.³⁶ Female subjects were tested at five different points during their cycle: early follicular, late follicular, mid-luteal, late luteal, and early follicular again.³⁶ Male subjects were tested the same number of times at similar time intervals.³⁶ A KT-1000 arthrometer was used to measure the amount of anterior knee displacement at 90 N and posterior displacement at 130 N.³⁶ Females had the largest spike of estradiol at visit two and three (late follicular and mid-luteal), and progesterone at visit three (mid-luteal).³⁶ No changes in estradiol and progesterone were found in the men.³⁶ No significant changes were found between testing sessions for anterior or posterior translation for female or male subjects, but when compared to each other females exhibited greater translation.³⁶ This research demonstrates that differences between genders exist for the amount of anterior

and posterior translation at the knee. The majority of research demonstrates that knee laxity varies at different points of the menstrual cycle.^{1,3,4,5,9,10}

NEUROMUSCULAR STIFFNESS

According to Schmitz and colleagues,⁴⁶ “joint stiffness is a biomechanical parameter that characterizes the deformation of the soft-tissue structures connecting one bone to another in response to applied load or torques.” Park et al.⁵ studied 26 healthy females who they tested during a single menstrual cycle to determine if significant changes in knee laxity/stiffness occur between three specified points during the menstrual cycle. Knee laxity measurements were determined with a KT-2000 knee arthrometer.⁵ The arthrometer also allowed for calculation of approximate linear stiffness by plotting the slope of a straight line to sections of the load-displacement curve.⁵ Researchers reported that an increase in anterior knee laxity occurred at different stages of the menstrual cycle and a decrease by 17% occurred for knee stiffness during ovulation when compared to the luteal phase.⁵

This study focused on the tensile properties of tissue in a static position more than a dynamic movement that requires stabilization by all ligaments and muscles of the knee.⁵ Knee stiffness needs to be evaluated during dynamic movements to determine if there is an increase or decrease in stiffness.⁵ This is important to study because non-contact knee injuries occur during active movements that utilize ligaments and muscles to help stabilize the joint. If an explanation that outlines the reason that dynamic laxity occurs, then steps can be taken to help correct the issue and hopefully reduce the risk of injuries.

MUSCULAR STRENGTH

Just as hormones' effect on knee laxity has been measured, so has their effect on force production of muscles.^{35,40,47,48,49,50,51} The majority of available research shows that hormones have no effect on force production of muscles.^{35,40,47,48,49} Few studies have reported inhibition of muscle function due to hormonal fluctuations.^{50,51}

As discussed above Hertel and colleagues³⁵ investigated whether or not female sex hormones affected knee laxity. In the same study, they analyzed muscular function at each phase of the menstrual cycle.³⁵ They determined that no significant differences existed between quadriceps and hamstring strength values at any point of the subject's menstrual cycle.³⁵

In 2001, Janse de Jonge and associates⁴⁰ reported findings they discovered when they investigated the menstrual cycle's effect on skeletal muscle. They recruited 19 female subjects and tested maximal isometric quadriceps, hamstring, and handgrip strength.⁴⁰ Each testing session aligned with a specific phase of the menstrual cycle: menses, late follicular, and luteal.⁴⁰ No significant differences in quadriceps, hamstring, or handgrip strength were identified.⁴⁰

A similar study of twenty-one female volunteers participated in testing sessions, which consisted of dynamic strength measurements of knee flexor and extensor muscles, throughout their menstrual cycle.⁴⁷ Researchers reported that neither of the muscle groups yielded any significant differences in muscle strength across the menstrual cycle.⁴⁷ Studies by Elliot and colleagues⁴⁸ and Abt and colleagues⁴⁹ failed to report any significant difference between muscle function through their subjects menstrual cycle.

Phillips and associates⁵⁰ investigated the effect of fluctuating hormones on the strength of the adductor pollicis. Twenty-seven subjects were recruited to participate in the study, which required each subject to complete trials three times a week during two menstrual cycles.⁵⁰ Each subject was asked to maximally contract the adductor pollicis muscle against a transducer.⁵⁰ The results showed that maximum voluntary force increased significantly during the follicular phase and a dropped at ovulation.⁵⁰

Sarwar and colleagues⁵¹ determined from twenty young women that significant differences exist between muscle strength production and phases of the menstrual cycle. Subjects were asked to complete a maximum voluntary contraction of the quadriceps muscle and hand grip strength.⁵¹ This procedure was completed weekly through two complete menstrual cycles.⁵¹ Testing was completed at early follicular, mid-follicular, mid-cycle, mid-luteal, and late luteal.⁵¹ It was reported that quadriceps strength peaked during the mid-cycle phase, with the greatest difference being between mid-cycle and late luteal phases.⁵¹ Handgrip strength was reported to be significantly greater for maximum voluntary contraction at the mid-cycle phase, with differences between mid-cycle and late luteal phases.⁵¹

VIDEO ANALYSIS

Video analysis has allowed for better understanding of an athlete's movements because of the ability to slow down or stop video clips of a movement for analysis.^{8,11,12,13,20,30,31,42,46,52} Researchers have the ability to monitor movements with increased accuracy due to the advancements in video analysis techniques. Reflective markers are often times attached to the participant's body during testing trials, which allow for better visual acuity of certain movements. The process works by videotaping

each testing session and then importing the data into a video editing program that allows a researcher to analyze movements, contact times, and joint angle measurements. One of the greatest advantages to using video analysis is the ability to collect video sequences without having to be present for collection; meaning that video clips of injuries can be collected after the time of injury for retrospective studies. Many studies that use this technique have collected clips from athletic organizations, patients, athletic trainers, physicians, and parents for athletic populations ranging from high school to professional.^{8,12,20,30,42}

Boden et al.⁸ collected video sequences of athletes at the time of ACL injury over a twelve year period from 1995-2007. Twenty-nine videos were accepted as meeting the inclusion criteria of appropriate video quality with an approximate sagittal or coronal (anterior or posterior) view of the athlete, view of foot-ground contact, unhindered view of the athlete, and no player-to-player contact with another player at time of injury.⁸ These 29 videos were compared to 27 control videos of athletes from similar levels of competition that performed comparable movements.⁸ There was no significant difference found in knee abduction at the initial contact phase of the athlete with the ground between the different groups, however the ACL-injured subjects experienced an increase amount of knee abduction after initial contact.⁸ The researchers also discovered that females (18 subjects) who incurred an ACL injury experienced an increased amount of knee abduction than their male (11 subjects) counterparts' did.⁸

In a similar study by Hewett et al.³⁰ videos were collected and analyzed that showed increased knee abduction angles occurred in ACL injured females more than non-injured female athletes did. They determined those athletes who incurred an ACL

injury experienced greater knee abduction and higher levels of lateral trunk movement.³⁰ The researchers believe the increased lateral trunk motion experienced in the subjects directly influences the amount of knee abduction that occurs during movement.³⁰

Krosshaug and colleagues²⁰ found through a similar collection of video sequences that female athletes experienced a greater knee abduction movement 50 milliseconds after initial contact with the ground than male subjects. In nine of the 17 female subjects, a “valgus collapse” was observed.²⁰ Valgus collapse was defined as the combination of a medial movement of the knee coupled with internal hip rotation, knee valgus, and external tibial rotation, which is believed to be a risk factor for ACL injuries.²⁰

In a study of three ACL injury scenarios video analysis was utilized to determine knee valgus movements during basketball, downhill skiing, and handball.⁴² Researchers determined that an increasing amount of knee valgus occurred at the time of injury.⁴²

Olsen et al.¹² undertook a prospective cohort study of ACL injuries. The group gathered subjects from the three upper divisions of Norwegian team handball during the 1998-1999 season.¹² Sixty teams were followed over the 12-month period.¹² If a subject received a knee injury that was suspected of being an ACL injury, they were immediately contacted by or referred to the researchers.¹² All ACL injuries were confirmed by either MRI or arthroscopic examination.¹² Each subject with a knee injury was asked to complete a short questionnaire for the researchers.¹² Some of the questions included the subject’s age, division, date of injury, how the injury occurred, position on the field and if surgery had been completed or planned.¹² Thirty-two ACL injuries occurred during this year. Only five of the 32 injuries could be used for video analysis.¹² The researchers were able to find 15 more appropriate videos from the 1988-1998 and 1999-2000

seasons.¹² Researchers were interested in determining if similar tendencies could be found between each video episode and the questionnaire.¹² Twelve of the twenty subjects were performing a “plant-and-cut” move with the majority of the movements occurring at a high rate of speed.¹² According to the results the subjects appeared to have lost control during their change of direction movement.¹² The researchers were able to conclude that two situations were responsible for ACL injuries (i.e. plant-and-cut faking movement or single leg landing from a jump shot).¹² All of the episodes were observed to have a forceful valgus collapse in conjunction with near full knee extension and slight internal/external tibial rotation during foot contact with the ground.¹²

Hewett and colleagues¹¹ performed three-dimensional preparticipation screenings for 205 female adolescent athletes. The participants were equipped with 25 retro-reflective markers at specific anatomical locations, which helped to identify particular movement patterns.¹¹ The participants were then asked to perform a jump-landing task.¹¹ The participants were followed through their athletic season where nine of the athletes received non-contact ACL injuries.¹¹ The nine participants that received an ACL injury displayed significantly different knee movements than the uninjured participants.¹¹ They experienced on average 8° more knee abduction and were determined to be at a 2.5 times greater risk of receiving an ACL injury than those who were not injured.¹¹

McLean and colleagues⁴¹ investigated the ability of 2-dimensional video analysis to accurately observe valgus knee motion in basketball players. Ten female NCAA basketball players were recruited as subjects for this study.⁴¹ Each subject completed a series of movements that increase the amount of valgus motion, while being videotaped via 3-dimensional and 2-dimensional (frontal) views.⁴¹ The researchers reported that 2-

dimensional video analysis was effective at evaluating valgus angles of female athletes during athletic movements, when taken from a frontal view.⁴¹

CONCLUSION

Ample evidence demonstrates that women are at a greater risk of experiencing a non-contact anterior cruciate ligament injury during different phases of the menstrual cycle.^{1-6,8,9} It has also been shown that the likelihood of sustaining an ACL injury from valgus collapse is high.^{30,42} Researchers have found that significant differences in ACL laxity exist across different phases of the menstrual cycle for female athletes.^{1,3,4,6,9,34} It has been determined that ACL laxity is directly affected by varying levels of estradiol, progesterone and testosterone, which all fluctuate immensely throughout the menstrual cycle.^{1,3,4,6,9,34} More specifically, ACL laxity changes as sex-hormone concentrations fluctuate throughout the menstrual cycle. This is important to comprehend because the ACL contributes 86% of the resistance to anterior translation of the tibia on the femur.³⁴ If for some reason the ACL performs at a decreased ability, injury is likely to result.

Video analysis allows for a better understanding of the mechanisms of injury for ACL injury by providing the opportunity to replay the mechanism of injury as many times as needed. It offers researchers the ability to review how and why an injury occurs while collecting objective data that can be analyzed for a better understanding of risk factors. The use of video analysis has been shown to be a beneficial tool for studying lower extremity kinematic motion and in this study is the cornerstone for data acquisition.^{8,11,12,13,20,30,31,42,46,52}

CHAPTER THREE: SUMMARY AND CONCLUSIONS

Anterior cruciate ligament (ACL) injuries are a problem of epidemic proportions within the world of female athletics. Many studies have investigated and reported ACL injury risk factors, including knee valgus angle and the menstrual cycle.^{1,2,3,4,6,7,10-29} The purpose of the current study was to determine if significant changes in valgus angle occur during different phases of the menstrual cycle. Ten female subjects were recruited for testing. Statistical analysis revealed that no significant changes in valgus angle occur during four different points within a subject's menstrual cycle ($p=.369$); first day of menses, mid-follicular, ovulation, and mid-luteal.

Future research should use daily hormone analysis to determine exact changes in phases of the menstrual cycle and three-dimensional video analysis, which will allow for interpretation of tibial rotation. By utilizing daily measurements, it may be possible to determine if a certain quantity of a specific hormone results in an increased amount of laxity. Multiple consecutive menstrual cycles should be studied to determine reliability of hormone levels. Subject recruitment is difficult to accomplish, but a larger population size will help to show trends of results.

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APPENDIX A:

**NORTHERN MICHIGAN UNIVERSITY
DEPARTMENT OF HPER**

CONSENT TO ACT AS A HUMAN SUBJECT

Subject Name (print): _____ Date _____

1. I hereby volunteer to participate as a subject in exercise testing. I understand that this testing is part of a study entitled: "*Changes in Knee Valgus Angle of Female Athletes During Different Phases of the Menstrual Cycle.*" The purpose of the study is to investigate the changes in valgus angle of the female knee at different points of the menstrual cycle.

I hereby authorize Eric J. Daniels, Dr. Randall L. Jensen and/or assistants as may be selected by them to perform on me the following procedures:

- (a) to have me perform for testing sessions consisting of four trials per session of a drop-jump maneuver. I will be required to stand atop a 30 cm box from which I will step down from. Once I land on the ground, I will then jump as high as I am able to as if I were jumping for an apple in a tree. I will be required to keep my arms in a neutral position, shoulders slightly flexed, elbows flexed and palms facing away from me.
 - (b) I understand that I will have markers placed on my hips, knees, and ankles. These markers will be filmed with a video camera during the performance of the exercises and the data used to determine my knee and ankle angles while landing and accelerating upwards.
 - (c) I also understand that I will provide a through history of my menstrual cycle for the previous 12 months so that the researchers are able to properly determine the different phases of my cycle.
 - (d) Total time of testing will require approximately 20-25 minutes of testing for each of the four testing days. This will require approximately 80-100 minutes of my time.
 - (e) I will also complete a PAR-Q screening survey to determine any health risks I may have that would prevent me from participating in the study.
2. The procedures outlined in paragraph 1 [above] have been explained to me.

3. I understand that the procedures described in paragraph 1 (above) involve the following risks and discomforts: temporary muscle pain and soreness is expected. However, I understand that I can terminate any test at any time at my discretion. Moreover, I should cease any test if I experience any abnormalities such as dizziness, light-headedness, or shortness of breath, etc. I also understand that this study includes a double leg landing task, which carries the risk of injury to the ankle and/or knee.
4. I have been advised that the following benefits will be derived from my participation in this study: aside from the educational benefit of learning force measurements testing or more instruction on the performance of the landing techniques, there are no direct benefits to me.
5. I understand that Eric J. Daniels, Dr. Randall L. Jensen and/or appropriate assistants as may be selected by them will answer any inquiries that I may have at any time concerning these procedures and/or investigations.
6. I understand that all data, concerning myself will be kept confidential and available only upon my written request. I further understand that in the event of publication, no association will be made between the reported data and myself.
7. I understand that there is no monetary compensation for my participation in this study.
8. I understand that in the event of physical injury directly resulting from participation, compensation cannot be provided.
9. I understand that I may terminate participation in this study at any time without prejudice to future care or any possible reimbursement of expenses, compensation, or employment status.
10. I understand that if I have any further questions regarding my rights as a participant in a research project I may contact Dr. Terry Seethoff, Dean of Graduate Studies of Northern Michigan University (906-227-2300) tseethof@nmu.edu. Any questions I have regarding the nature of this research project will be answered by Dr. Randall Jensen (906-227-1184) rajensen@nmu.edu or Eric Daniels (207-514-3299) edaniels@nmu.edu.

Subject's Signature: _____

Witness: _____ Date: _____

APPENDIX B:

Medical History Questionnaire

Participant's I.D. # _____

Name: _____ Date of Birth: ___/___/_____
(For identification of survey only, will be anonymous after selection process)

1. Age: _____
2. Height: _____ (cm)
3. Weight: _____ (kg)
4. Have you ever experienced a leg injury? Yes: _____ No: _____
 - Was it within the last 6 months? Yes: _____ No: _____
 - Which leg? Right: _____ Left: _____ Both: _____
 - If Yes, what type of injury (Please select all that apply):
 - ___ Bone Fracture, Where? _____
 - ___ Ligament Sprain, Where? _____
 - ___ Muscle Strain, Where? _____
 - Did this injury require surgery? Yes: _____ No: _____
 - o What type of surgery:

5. Do you have a regular menstrual cycle? Yes: _____ No: _____

Typically, how many days from the beginning of one period to the next : _____

Have you missed a period in the past 3 months? Yes: _____ No: _____

 - o If yes, how many were missed and when?

Are you pregnant? _____ Yes: _____ No: _____

2012

January

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

February

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29			

March

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

April

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

May

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

June

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

July

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

August

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

September

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

October

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

November

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

December

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					