International Journal of Kinesiology & Sports Science
ISSN: 2202-946X
www.ijkss.aiac.org.au

Biomechanical Differences in Knee Valgus Angles in Collegiate Female Athletes Participating in Different Sports

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ARTICLE INFO

Article history
Received: January 19, 2019
Accepted: March 24, 2019
Published: April 30, 2019
Volume: 7 Issue: 2

Conflicts of interest: None
Funding: None

ABSTRACT

Background: Dynamic knee valgum is a major risk factor in ligamentous injuries of the knee. Different sports have higher rates of knee ligament injury than others and females experience knee non-contact ligament injuries at higher rates than their male counterparts. **Objectives:** The purpose of this study was to investigate the lower extremity biomechanics of genu valgum in female collegiate athletes of various sports while performing a drop jump test. This information may provide those designing individualized prevention programs assistance in reducing risk of knee ligamentous injury during jumping tasks. **Methods:** Current members of Idaho State University's women's basketball, soccer, and softball teams were evaluated for this study. Thirty-seven athletes participated. Motion capture reflective markers were placed bilaterally on the lower extremities to allow for analysis of knee biomechanics during a double-leg drop jump test. The angles of knee valgum in the frontal plane were calculated and analyzed between sport groups. **Results:** Female athletes of different sports displayed statistically significant differences in knee angles for both right, and left knees. Post hoc analysis with a Bonferroni adjustment revealed that basketball players utilized a more valgus right knee angle compared to both soccer and softball players and a more varus left knee angle compared with softball players. **Conclusions:** Our study suggests that collegiate-level female basketball players have an increased risk of right leg non-contact knee ligament injury during jump landing maneuvers when compared to collegiate level softball and soccer players due to increased knee valgus movements during the drop jump test. Collegiate-level female basketball players may benefit from biomechanical exercise interventions designed to decrease right knee valgus moments in jumping and landing to decrease their risk of injury.

Key words: Knee, Female, Athletes, Ligaments, Genu Valgum, Knee Injuries

INTRODUCTION

Dynamic genu valgum, also referred to as knee abduction, is a risk factor for ligamentous injury of the knee, especially the anterior cruciate ligament (ACL) (Hewett, Ford, Hoogenboom, & Myer, 2010; Hewett et al., 2005; Numata et al., 2018). Dynamic genu valgum occurs as the knee moves medially in the frontal plane with associated hip adduction and internal rotation and tibial abduction and external rotation (Hewett et al., 2010). These combined motions place increased, and potentially injurious, tensional stress on the medial collateral ligament and the ACL (Magee, 2013). This potential injurious position increases the stabilizing load on the ligamentous structures and can result from muscular weakness or insufficient neuromuscular control (Ford, Myer, Toms, & Hewett, 2005). Poor neuromuscular control leads to the inability of the knee to maintain alignment and absorb sufficient ground reaction force during dynamic activities. This inability to absorb ground reaction force creates increased knee valgus moments, increases stress on ligaments, and leads to possible ligament injury or failure (Hewett, Paterno, & Myer, 2002).

The majority of ACL injuries in female athletes result from non-contact forces. These non-contact ACL injuries account for 60% of female ACL injuries. In contrast, the majority (59%) of male athlete ACL injuries are due to contact-related incidents. (Agel, Rockwood, & Klossner, 2016). The National Collegiate Athletic Association (NCAA) Injury Surveillance Program reported ACL injuries as the most

Published by Australian International Academic Centre PTY.LTD.

http://dx.doi.org/10.7575/aiac.ijkss.v.7n.2p.8

common severe injury reported among women's lacrosse (28.1%), women's soccer (25.9%), women's volleyball (25.7%) women's basketball (20.8%), women's softball (14.8%), and women's gymnastics (13.9%) during the 2009-2010 and 2014-2015 academic years (Kay et al., 2017). ACL injuries accounted for 2.6% of all severe NCAA athletic injuries (Hootman, Dick, & Agel, 2007). The National Athletic Trainers' Association reported, in their 2018 position statement on prevention of anterior cruciate ligament injuries, that female athletes are at 1.5 to 4.6 times greater risk for ACL injury compared to their male counterparts during sport (Padua et al., 2018).

Females overall suffer ACL injuries 4 to 6 times that of males (Hewett et al., 2005). Several factors may explain this trend. In a study of 215 intercollegiate athletes, females demonstrated more high-risk frontal plane landing mechanics at the knee joint during dynamic activities than male athletes of similar sports (Lam & McLeod, 2014). These differences may be a result of lower baseline conditioning levels, anatomic and physiologic factors, structural differences (i.e. ligamentous laxity, bony alignment and shape, ACL size), and differences in muscular flexibility (Hutchinson & Ireland, 1995; Myer, Ford, Khoury, Succop, & Hewett, 2010; Nilstad, Krosshaug, Mok, Bahr, & Andersen, 2015). Insufficient preparatory neuromuscular activation to control the knee, during landing tasks, has been observed in female athletes (Chappell, Creighton, Giuliani, Yu, & Garrett, 2007; Nilstad et al., 2015). This lack of biomechanical control often results in increased knee valgus and hip internal rotation (Chappell et al., 2007). The ability of female athletes to control knee alignment during sport is especially important. Just a two-degree difference in knee valgus can alter forces at the knee joint by an individual's entire body weight (Boden, Sheehan, Torg, & Hewett, 2010).

Several studies have analyzed the relationship between participation in different sports and their associated risk of ACL injury (Agel et al., 2016; Gornitzky et al., 2016; Munro, Herrington, & Comfort, 2012; Taylor et al., 2017). Soccer, basketball, football, and lacrosse have been identified as high-risk sports for both genders. For females, ACL injury risk is highest in soccer, followed by basketball and lacrosse (Agel et al., 2016; Gornitzky et al., 2016; Joseph et al., 2013). ACL injury rates differ between sports, which may indicate kinematic and biomechanical differences between athletes competing in different sports. Motion analysis can measure these biomechanical differences between athletes during a sport specific task, such as a drop jump.

The drop jump test (DJT) is effective in replicating sport specific functional tasks of jumping and landing on either one or two feet in an aggressive manner (Munro et al., 2012). The DJT has been used to measure knee biomechanics and to establish normative data for dynamic knee valgus (Cowan & Crossley, 2009; Hewett et al., 2005; Jackson, Beach, & Andrews, 2017; Myer et al., 2010). An analysis of 50 physically active, asymptomatic females between the ages of 18 and 28 years of age, knee valgus angles of 7-13 degrees were considered normal during a DJT (Herrington & Munro, 2010).

The purpose of this study was to investigate the lower extremity biomechanics of the knee in female collegiate athletes of various sports while performing a DJT. This information may provide, those designing individualized injury and training programs for these athletes, assistance in reducing knee ligamentous injury risks during jumping tasks.

METHODS

Participants and Study Design

Current members of Idaho State University's women's basketball (n=9), soccer (n=13), and softball (n=15) teams were evaluated for this descriptive study comparing the differences in landing mechanics between different sport athletes. Consent was received from team coaches to recruit their athletes to participate in the study. All procedures were reviewed and approved by the Institutional Review Board at Idaho State University. Participants signed written informed consent for participation and were between the ages of 18 - 30 years old. Participants were excluded from this study if they had a history of hip or knee injuries within the three months prior to the study, experienced current hip or knee pain during activity, had undergone lower extremity surgery within the past year, had neurologic or medical disorders preventing completion of the jump landing task, were currently taking medication for pain in the lower extremities, or if they were pregnant (Distefano, Blackburn, Marshall, & Padua, 2009; Mizner, Kawaguchi, & Chmielewski, 2008; Tate, Milner, Fairbrother, & Zhang, 2013).

Instrumentation

Three-dimensional motion analysis was performed using a computer-aided video motion capture system (Vicon Bonita Motion Capture, Vicon Motion Systems Ltd. Denver, Colorado, United States). Kinematic data was sampled at 250 Hz and recorded digitally on an encrypted Dell laptop computer (Dell Computer Corporation, One Dell Way, Round Rock, Texas, United States). Reflective markers on specific bony landmarks were used to calculate motion of the hip, knee, and foot in the sagittal, frontal, and transverse planes (Pollard, Sigward, Ota, Langford, & Powers, 2006). Protected information of each participant was entered and kept on an encrypted computer and was secured on campus in a locked office. Paper copies for backup purposes were kept in a locked file cabinet in a locked office. All participants were assigned a randomized number during data collection to maintain anonymity, and only the primary and secondary investigators had access to the protected information. Data was shared and identified by randomized numbers only.

Procedures

Prior to testing, each participant completed a history questionnaire including their age, race, dominant leg (defined as the leg which the participant chose to kick a ball for distance), and what sport they participated in (Distefano, et al., 2009; Ford, Myer, & Hewett, 2003; Mizner et al., 2008).

Participants were asked to wear appropriate clothing that allowed for access to marker landmark locations and for the thigh and leg visibility during trials. Participants were not required to wear a certain top as long as the posterior superior iliac spines (PSIS) could be made visible. Inter-anterior superior iliac spine (ASIS) distance, leg length, ASIS-trochanter distance, knee width, ankle width, and tibial torsion were measured with a tape measure. Height and weight were also measured. All measurements for each participant were input into the Nexus 2.2 system (Vicon Motion Systems Ltd. Denver, Colorado, United States) (See Table 1).

Testing procedures began with the participants warming-up for five minutes on a stationary bicycle. Reflective markers were placed bilaterally on the following anatomical landmarks: PSIS, ASIS, greater trochanter, thigh, tibial tuberosity, lateral joint line of the knee, lower leg, lateral malleoli, calcaneus, and second metatarsal head (see image 1). After placing the markers, standing data calibration on the Nexus 2.2 system and the Vicon Bonita Motion Capture cameras were completed.

Participants were instructed to perform the DJT as follows: "Drop directly down off the stool and immediately perform a maximum vertical jump and reach both arms up as if to touch the ceiling". Participants were instructed to keep elbows bent and hands at shoulder level when dropping to ensure reflective marker visibility to the cameras. The same fixed-height (30 cm) stool was used for all participants. Each participant completed one practice drop jump from the 30 cm stool. After one practice drop jump, each participant completed three tested drop jumps in succession with the motion analysis (Mizner et al., 2008; Tate et al., 2013).

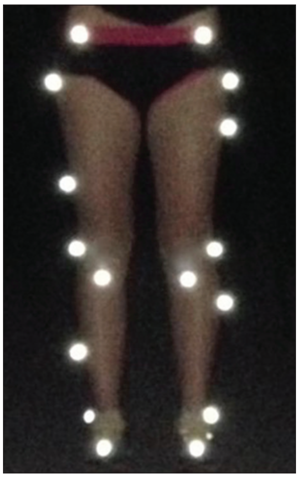

Image 1. Placement of reflective markers
Description: Marker placement for motion analysis of the Drop Jump Test

Data

The dependent variable evaluated was peak knee valgus at the end of deceleration (as measured by the subjects' knee valgus angles bilaterally) of each knee. The deceleration phase was defined as the time between initial toe contact and the deepest point of the landing (lowest vertical point that the ASIS reached) (Noyes, Barber-Westin, Fleckenstein, Walsh, & West, 2005). The trial resulting in the highest vertical jump, from each participant with all markers visible throughout the jump, was chosen for analysis (See Table 2).

Statistical Analysis

A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in knee angles for female athletes in the three different sports (basketball, soccer, softball). The data were normally distributed at each phase of the jump, as assessed by Shapiro-Wilk test ($p>.05$).

RESULTS

Female athletes of different sports displayed statistically significant differences in knee angles for both right, $F(4, 68)= 4.508, p=0.003$) and left knees $F(4, 68)= 2.646, p= 0.011$). Post hoc analysis with a Bonferroni adjustment revealed that basketball players utilize a more valgus right knee angle compared to both soccer and softball players (9.26, $p = 0.014$ and 11.88, $p=0.001$) and a more varus left knee angle compared with softball players (11.56, $p=0.003$). (See figure 1).

DISCUSSION

The current study was designed to investigate the difference in average frontal plane knee angles (varus and valgus) in female athletes competing in basketball, soccer, and softball at an NCAA Division I level. Female basketball players fell

Table 1. Participant Demographics

Sports	Average Age (years)	Average Height (inches)	Average Weight (pounds)	Average BMI	Right Leg Dominant (percentage)
Basketball	19.78	71.36	178.11	25.2	78
(SD)	(1.5)	(2.2)	(17.7)	(2.4)	
Soccer	19.23	65.94	149.38	24.8	85
(SD)	(1.2)	(1.9)	(10.1)	(2.2)	
Softball	19.2	66.95	165.6	26.66	100
(SD)	(1.4)	(2.3)	(26.4)	(4.6)	

Description: Average age and anthropometric measures of participants of each individual sport and percentage of those identifying as being right leg dominant in each sport

Table 2. Average Knee Angles (measured in degrees)

Sport	Static		Initial Contact		Deepest Squat	
	Right	Left	Right	Left	Right	Left
Basketball	9.973	6.396	13.232	-7.732	18.83	-16.987
(SD)	(3.6)	(3.6)	(4.5)	(6.4)	(13.8)	(9.4)
Soccer	7.303	8.339	1.794	-2.647	5.152	-6.327
(SD)	(2.5	(3.1)	(4.3)	(5.3)	(9.8)	(14.5)
Softball	8.443	8.559	-0.718	5.104	-1.34	2.716
(SD)	(4.4)	(4.2)	(9.0)	(8.6)	(15.9)	(20.1)

Description: Average knee angles between sports at three points in the landing phase of the Drop Jump Test: at static standing; at initial toe contact with the floor; and at the point of deepest squatting prior to accelerating upward to jump. Positive values represent valgus knee positions with negative values representing varus knee positions

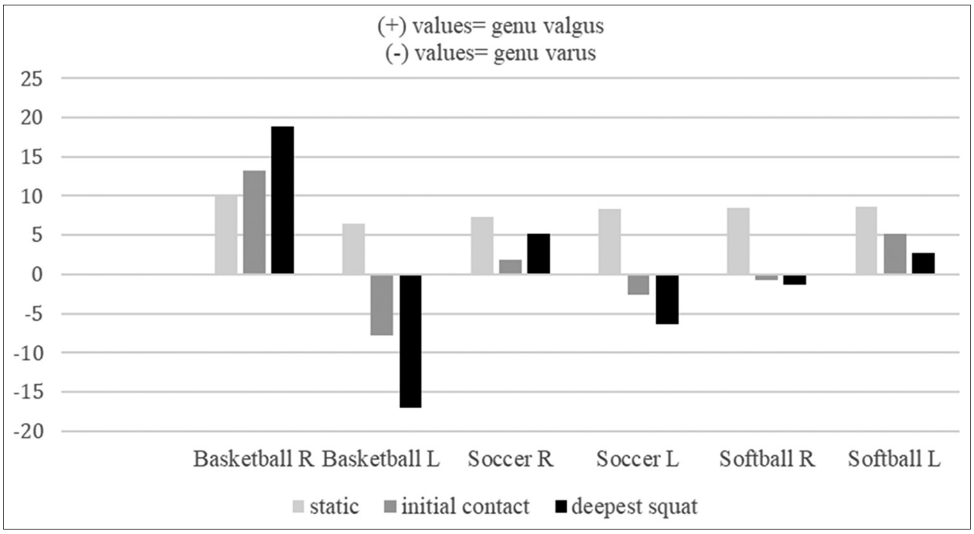

Figure 1. Graphic depiction of average knee angles

Description: Visualization of the extent of differences in average knee angles between sports at three points in the landing phase of the Drop Jump Test: at static standing; at initial toe contact with the floor; and at the point of deepest squatting prior to accelerating upward to jump. Positive values represent valgus knee positions with negative values representing varus knee positions

into increased right knee valgus as compared to soccer and softball players. Normative data indicate that knee valgus angles should be symmetrical and within seven to thirteen degrees (Herrington & Munro, 2010). Our results showed the average female basketball player had 18 degrees of right knee valgus at the peak of their deepest squat, suggesting they have a higher risk of an ACL injury on their right leg compared to other sports and leg. The majority of female basketball players in our study were right leg dominant. Even though leg dominance was assessed in this study, it was not investigated as a variable. The study sought to discover a trend, if one existed, between athletes of different sports in a jump landing maneuver. Our results are consistent with a study by Ford et al. (2003) that demonstrated an increased valgus knee angle in the dominant leg of female basketball players. The two basketball players who reported left leg dominance also presented with a right knee valgus angle during the drop jump. This may suggest that leg dominance in female basketball players may not be related to increased knee valgus, but further studies specifically studying the variability of leg dominance between female collegiate sport athletes would need to be performed.

Determining leg dominance, can be difficult when comparing various sports. Leg dominance is assessed by asking the player which foot an athlete would kick a ball, this technique may not be applicable to non-kicking sports. Soccer players kick the ball with their dominant leg, but plant their non-dominant leg which puts their non-dominant leg in a more forward position. Basketball players are commonly instructed to lead with the same leg as their shooting arm, which puts their dominant leg slightly forward (Okazaki, Rodacki, & Satern, 2015; Pollard, Sigward, & Powers, 2010). Volleyball players utilize a staggered stance but forward leg is not always specified (Johnson et al., 2010). These subtle differences between sport biomechanics may be a reason for confounding results of leg dominance when performing a drop jump.

Limb dominance makes up only 15% of the factors contributing to knee valgus (Nilstad et al., 2015). Leg dominance is difficult to define due to sport specific activities, but leg dominance is frequently investigated during drop jump research in assessing risk for ACL injuries. One study found that females demonstrated an increased knee valgus in their dominant leg compared to males (Ford et al., 2003). Other studies found female athletes were at higher risk for non-contact injuries in their non-dominant leg or planted foot (Brophy, Silvers, Gonzales, & Mandelbaum, 2010; Aizawa et al., 2018). Yet additional studies have shown no difference in risk between dominant and non-dominant lower extremities in female athletes (Mokhtarzadeh et al., 2017; Nilstad et al., 2015). Conflicting results across studies suggest the need to investigate multiple underlying causes for injuries in addition to leg dominance.

Many studies suggest females are at a greatest risk for an ACL injury when playing soccer and basketball (Agel et al., 2016; Gornitzky et al., 2016; Joseph et al., 2013). The underlying reason for the increased risk in these two sports is still to be determined. Sport-specific movements and activities may contribute to biomechanical differences in jump landing maneuvers. In considering the biomechanics of the double-leg DJT, our results suggest that female basketball players have a higher risk for ACL injury due to increased right knee valgus motion during the DJT. Training programs designed to decrease the incidence of ACL injuries may benefit athletes in decreasing injury risk from biomechanical differences. Other risk factors in non-contact ligamentous injuries should be analyzed (Chappell & Limpisvasti, 2008; Hewett, Ford, & Myer, 2006; Mandelbaum et al., 2005).

Munro, Herrington, and Comfort (2012) compared knee angles in athletes while performing a DJT using a double-leg versus a single-leg landing strategy. Contrary to our results, they found no significant difference between female soccer players and basketball players during the bilateral leg DJT. Their results showed that basketball players had increased valgus knee angles with single-leg landing strategies compared to soccer players. They concluded this single-leg difference could explain an increased risk of injury in basketball players over soccer players.

The other significant finding was that basketball players' left lower extremities utilized a more varus knee position than softball players. With valgus positions being implicated in many ligament injuries, the more knee varus position is more stable with less strain and stress on the ligaments. This could suggest that basketball players's left legs are more stable to provide a stronger base to jump from. When performing a DJT with both legs, basketball players likely shift to the more stable leg to provide upward thrust force and stability. Further analysis would be required to investigate this claim.

A number of limitations could have affected the quality of our findings. The use of convenient sampling of the local collegiate sports teams, analyzing data from only three sports, and small sample sizes for each sport limits the generalizability of this study. Measuring knee valgus angles at the knee is a combined movement of frontal plane knee adduction, transverse plane femoral internal rotation, and sagittal plane knee and hip flexion. This study only investigated the frontal plane movements. By only considering the frontal plane, we did not examine the effects that knee and hip flexion contribute to the stresses at the knee joint. Our study focused specifically on knee valgus angle and did not study other variables such as flexion angles, muscle activation, landing strategy or landing forces, which have also been investigated when considering risk of ACL injuries. Another limitation to our study is the use of the DJT. This test is a tool used to standardize the movement at the knee for testing across sports, however, it is not a traditional movement in all sports. Mechanics of the knee could be assessed when performing traditional movements of the specific sports such as rebounding a basketball or cutting and kicking drills performed in soccer.

This study was designed to identify the frontal plane motion of the knee in female collegiate various sport athletes during landing and then maximally jumping. Evidence suggests a correlation between increased valgus knee angles and ACL injuries (Hewett et al., 2005). However, this correlation has not been proven in randomized controlled trials. Further investigation into specific sports and the stresses that dominant vs non-dominant lower extremities receive during specific sports activities, may further explain the differences in knee valgus angles and the associated risk for ACL injuries. Larger sample sizes across multiple sports, and utilizing more than one individual university team for each sport would increase the magnitude and generalizability of the results. In addition, future studies could include a randomized controlled trial of single-leg landings versus double-leg landings to analyze the presence of frontal plane knee movement and leg dominance and their relevance in biomechanical differences in female athletes of multiple sports.

CONCLUSION

The results of this study may assist in identifying which female collegiate athletes, between basketball, soccer, and softball athletes, are at an increased risk for injury and to identify which populations require early biomechanical intervention to prevent future injuries. Our study suggests that collegiate-level female basketball players have an increased risk of right leg non-contact ACL injury during landing maneuvers when compared to collegiate level softball and soccer players due to increased knee valgus moments during the drop jump test. Collegiate-level female basketball players may benefit from exercise interventions designed to decrease right knee valgus moments in jumping and landing to decrease their risk of injury.

ACKNOWLEDGEMENTS

We acknowledge with gratitude the efforts of the Idaho State University Physical Therapy Doctoral students who participated in this study in assisting in data collection, research, and writing. The following students assisted over the course of the project: Eric Hunter, Derek Labrum, Jake Menotti, Sam Tibbs, Mitch Beckstead, Steffani Bush, Nick Davis, Hope Hampton, Chris Kendrick, Nkem Nkele, Sarah Cairns, Zach Maas. Conor Smith, Brett Arnell, and Jacob Bratton.

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