

5-6-2015

# Neuromuscular Characteristics of Division I Collegiate Female Athletics

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## Recommended Citation

Murphy, Robyn, "Neuromuscular Characteristics of Division I Collegiate Female Athletics" (2015). *Master's Theses*. 763.  
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# Neuromuscular Characteristics of Division I Collegiate Female Athletes

Robyn Elise Murphy

B.S., Quinnipiac University, 2012

A Thesis

Submitted in Partial Fulfillment of the

Requirement for the Degree of

Master of Science

At the

University of Connecticut




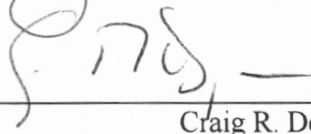
APPROVAL PAGE

Master of Science Thesis

Neuromuscular Characteristics of Division I Collegiate Female Athletes

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University of Connecticut  
2015

## Acknowledgements

Dr. Lindsay DiStefano: Thank you for being understanding with every obstacle I may, or may not have, created, and for challenging me in the best way possible for the past two years. I know there must have been times when you had your doubts, because I sure did. But I could not be happier with how my education at UConn is shaping up to be. I have you to thank for that.

Dr. Giselle Aerni: Thank you for being a faculty member, and saving me from a whole lot of paperwork. I truly appreciate your advice and feedback on my thesis, as well as professionally and personally.

Catie Dann: Thank you Catie for your brilliant ideas and feedback you've already given me. I am thankful that I have you as a wonderful role model, both clinically and academically.

Dr. Craig Denegar: Thank you for serving on my committee and being the most patient statistics professor ever. I actually remember a thing or two, and without your incredible tolerance I would not have a shred of knowledge of statistics.

Hayley Root: Words cannot begin to describe how appreciative I am for your guidance, assistance, and general awesomeness. I have you to thank for everything. I appreciate the ridiculous number of hours you've dedicated to editing, revising, re-editing, and meeting with me for my thesis. As well as your continued assistance with my data collection and defense. It has been a long journey and I'm happy to see that we've both made it out alive. Thanks again.



## Table of Contents

Chapter 1: Review of Literature	
1. Lower Extremity Injury.....	6
I. Epidemiology	
i. Anterior Cruciate Ligament	
ii. Ankle	
2. Risk Factors.....	10
I. Non-Modifiable	
i. Anatomy	
ii. Previous Injury	
II. Modifiable	
i. Neuromuscular	
ii. Biomechanics	
iii. Body Mass Index	
iv. Hormones	
v. Environmental	
vi. Other	
vii. Gender Differences	
3. Injury Epidemiology by Sport.....	23
I. Women's Basketball	
II. Women's Soccer	
III. Women's Volleyball	
IV. Sport Comparison	
4. Injury Risk Screening Tools and Injury Prevention Programs.....	32
5. Conclusion.....	40
Chapter 2: Introduction.....	42
Chapter 3: Methods.....	44
Chapter 4: Results.....	49
Chapter 5: Discussion.....	56
Chapter 6: References.....	64

## ABSTRACT

This study investigated differences in movement technique and ankle range of motion in female collegiate basketball, soccer, and volleyball athletes and the potential need to customize injury prevention programs athletes based on sport-based differences. Forty-five collegiate female athletes volunteered to participate in this study (age= $20 \pm 2$  years, mass= $68.7 \pm 11.1$ kg, height= $171.6 \pm 9.4$ cm). Athletes were members of a university basketball, soccer, or volleyball team. Ankle dorsiflexion range of motion was measured in non-weight bearing in knee extension, non-weight bearing in knee flexion, and weight bearing lunge test. A jump-landing task was scored using the Landing Error Scoring System (LESS) was also performed. Chi-square tests were performed on each LESS error between teams. Separate one-way ANOVAs were used to determine if previous ACL or ankle injury history affected LESS score or ankle range of motion. A one-way between subjects ANOVA was performed to determine if ankle dorsiflexion range of motion influenced risk classification. We did not observe a significant difference between sports for the composite LESS score ( $P > 0.05$ ). A greater proportion of basketball participants exhibited the “knee flexion at initial contact” error than the two other sports ( $P = 0.043$ ). There were no significant differences between ACL or ankle injury history and LESS score or ankle ROM ( $P > 0.05$ ). Participants with less than five degrees of NWB-KF ankle dorsiflexion had significantly higher LESS scores ( $P = 0.001$ ). The findings reveal an association between less ankle dorsiflexion and poor lower body movement patterns. These results indicate the potential importance of incorporating ankle mobility exercises in training programs for collegiate female athletes to decrease the incidence of lower extremity injury.

## **CHAPTER 1: Review of Literature**

### **LOWER EXTREMITY INJURY**

#### **Epidemiology**

Sport-related injuries are extremely common at the collegiate level. Between 1988 and 2004, there were over 182,000 injuries recorded in 15 NCAA sports, based on data collected by the National Collegiate Athletic Association Injury Surveillance System.<sup>1</sup> Those sports include men's baseball, men's and women's basketball, women's field hockey, men's football, men's and women's gymnastics, men's ice hockey, men's and women's lacrosse, men's and women's soccer, women's softball, women's volleyball, and men's wrestling. Practices and games account to more than one million injury exposures. There is one injury every two games, and one injury every five practices for a team of 50 participants.<sup>1</sup> These numbers demonstrate the substantial need for injury prevention in collegiate sports.

More than 50% of sport-related injuries in the NCAA occur to the lower extremity<sup>1</sup>, including acute and overuse injuries to the hip, thigh, knee, lower leg, ankle, and feet. Most lower extremity injuries occur to the knee and ankle joints. Anterior cruciate ligament is one of the most common severe knee injuries in sports.<sup>2,3</sup> These injuries are disabling, painful, and many patients undergo surgery. Ankle sprains are the most common musculoskeletal injury in athletic, military, and general populations.<sup>1</sup> Due to the frequency of ankle sprains and the devastating effects of ACL injuries, these two injuries require more attention in an athletic population.

### *Anterior Cruciate Ligament*

In the United States, there is an estimate of 250,000 ACL tears and 100,000 reconstructions, annually.<sup>4-6</sup> Data collected over 16 years in collegiate athletics reported approximately 5,000 ACL injuries in fifteen sports.<sup>1</sup> Seventy to eighty percent of ACL injuries occur with a non-contact mechanism.<sup>6,7</sup> A non-contact ACL tear is classified as a tear to the anterior cruciate ligament with no physical contact with another player.<sup>8,9</sup> Mechanisms that result in a non-contact ACL tear include changing direction or cutting maneuvers combined with deceleration, landing from a jump in or near full knee extension, pivoting with knee near full extension with a planted foot, knee hyperextension or hyperflexion.<sup>8,9</sup> These mechanisms commonly occur in sports, therefore many research efforts have been made to identify the risk factors associated with an ACL injury. Through identification and modification of injury risk factors associated with ACL injuries, prevention of the devastating injury and the long-term consequences associated with them may be avoided.

There are a number of expenditures with the anterior cruciate ligament, including financial loss, and time away from work, school, or athletics. These patients may also suffer from long-term consequences including pain, swelling, instability, or osteoarthritis.<sup>6</sup> The estimated cost of an ACL injury, including diagnostic tests, surgery, and rehabilitation is more than \$3 billion, annually within the United States.<sup>7</sup> Conservative cost is between \$11,500, and \$17,000 per case.<sup>4</sup> Average time loss from activity following an ACL injury can be 6 months, or longer.<sup>7</sup> Following ACL reconstruction, fewer than 50% of patients return to play within a year, less than 85% return within 2 years, 24% of patients will change sport, and 11% will discontinue sport related activities.<sup>6</sup> Many athletes do not return to their pre-injury levels of participation, despite aggressive rehabilitation.<sup>10</sup>

Long-term consequences of ACL or lower extremity injuries include chronic knee instability, concomitant injuries, such as meniscus tears and cartilage injuries, and premature osteoarthritis (OA).<sup>6,7</sup> Approximately 50% of ACL-injured patients exhibit evidence of OA associated with pain and functional impairment within 20 years after the original injury, despite optimal surgical or nonsurgical management.<sup>6,11</sup> Postsurgical functional limitations include swelling, pain, instability, decreased range of motion, and muscle weakness.<sup>12-14</sup> This growing list of complications highlights the critical need for primary ACL injury prevention.

### *Ankle*

Due to the high frequency and reoccurrence rate of ankle injuries, athletes may also benefit from primary ankle injury prevention measures may be necessary. Lateral ankle sprains are the most common lower extremity injury in sport participation.<sup>1,15,16</sup> Over 16 academic years, ankle ligament sprains accounted for 14.8% of all reported injuries, and therefore are the most common problem in college athletics.<sup>1</sup> The ankle joint absorbs the mechanical loads from the constant interaction of the individual with the playing surface and player-to-player contact.

Approximately 85% of all ankle sprains result from an inversion mechanism, and damage to the lateral ligament complex.<sup>15,17</sup> Damage to the lateral ankle ligaments result in pain, swelling, and decreased ankle dorsiflexion range of motion.<sup>15,18,19</sup> Furthermore athletes have two-times the risk of suffering from a recurrent ankle sprain within one year.<sup>20</sup> Agel et al,<sup>21</sup> reported that 30% of ankle ligament injuries were recurrent in collegiate women's basketball.

The cost of diagnosis, treatment, and loss of work productivity following an ankle sprain is high.<sup>22</sup> Twenty-five percent of all people who sustain an ankle sprain are unable to attend school or work for more than 7 days following the injury.<sup>22</sup> Chronic ankle instability (CAI) results in 'giving way' and feelings of ankle joint instability, perceived ankle instability,

mechanical ankle instability and/or recurrent ankle sprains.<sup>22-25</sup> CAI may cause of post-traumatic ankle joint osteoarthritis.<sup>22,26-28</sup> In addition, CAI can alter central mechanisms of motor control, leading to an increased risk of falls.<sup>22,29,30</sup> Chronic symptoms are one of the most common limiting factor affecting continued athletic participation.<sup>24</sup>

The repercussions related to ankle injuries are costly, long lasting, and modifiable. Following a lateral ankle sprain, ankle dorsiflexion range of motion becomes restricted due to pain, swelling, and limited arthrokinematics.<sup>18,31</sup> Restricted ankle dorsiflexion has been suggested to increase the risk of an ACL injury.<sup>32</sup> Therefore exercises and treatments to restore ankle dorsiflexion is important following an ankle injury.

Ankle dorsiflexion can be measured in both non-weight-bearing and weight-bearing positions. Weight-bearing measures are considered to be a more accurate reflection of available dorsiflexion range of motion during functional activities than non-weight-bearing positions.<sup>33</sup> Methods of measurement include the use of a standard goniometer or an inclinometer. A goniometer is an inexpensive tool and frequently used in clinical settings. However this tool requires a degree of expertise, to accurately position the goniometer's axis with the joint fulcrum and align the two arms with established landmarks. An inclinometer uses a dial, bubble, or digital display to provide the angle of the slope relative to the ground. This tool is more expensive than a goniometer, but requires less skill to accurately measure the range of motion. Obtaining accurate measures of ankle range of motion can help further injury prevention screening and exercise-based programs to reduce lower extremity injury in sports.

Lower extremity injuries are a burden, especially to the athletic population. Treatment, rehabilitation, and surgical intervention may not assure return to pre-injury function. Therefore

injury prevention measures are warranted to reduce injury risk, and lessen the physical, emotional, and economic expenses that participating in sports carries.

## **RISK FACTORS**

To further analyze the cause and effect of these lower extremity injuries, the risk factors for injury must be explained. Risk factors can be divided into modifiable and non-modifiable factors.

### **Non-modifiable Injury Risk Factors**

#### ***Anatomy***

A single joint should not be considered as an isolated component to evaluate risk factors for lower extremity injury. The trunk, pelvis, hip, knee, and ankle should all be considered in their relationship to resultant knee joint mechanics.

*Pelvis/Trunk Alignment* The position of the pelvis in relationship to the trunk may predispose an individual to injury. The pelvis can rotate anteriorly and posteriorly in comparison to the trunk. An anterior pelvis tilt puts the hip into a flexed, internally rotated, and anteverted position. This position lengthens and weakens the hamstrings and changes the moment arms of the gluteal muscles.<sup>8,34</sup> The hamstring musculature prevents static and dynamic genu recurvatum and prevents anterior tibial displacement.<sup>35</sup> Anterior pelvic tilt also increases genu valgus and subtalar pronation.<sup>35</sup>

The articulation of the femur at the acetabulum also affects pelvis and trunk alignment. Femoral torsion is the angle between the axis of the femoral neck and a transverse line through the posterior aspect of femoral condyles. Femoral anteversion is an increase in angle, and may cause an inefficiency of the gluteus medius through a decrease in the internal moment arm. A

weak gluteus medius may influence dynamic valgus collapse because of the muscles' inability to keep the hip abducted, especially during landing, cutting, and changing directions.<sup>8</sup>

*Q-Angle* The Q-Angle is the angle formed by a line directed from the anterior-superior iliac spine to central patella and a second line directed from the central patella to tibial tubercle. A high Q-angle may alter the lower limb biomechanics and places the knee at a higher risk to static and dynamic valgus stresses.<sup>36,37</sup> A study<sup>38</sup> has shown that female basketball players with knee injuries had a mean Q-angle greater than non-injured players. Conversely, another study<sup>39</sup> found that static Q-angle measures did not appear to predict either knee valgus angles, neuromuscular patterns or ACL injury risk during dynamic movements. Pantano et al,<sup>40</sup> demonstrated that peak knee valgus during a single leg squat and static knee valgus were not significantly greater in young college athletes with higher Q-angle compared to those with lower Q-angle. These college athletes with a larger Q-angle, however, had significantly greater pelvis width to femoral length ratios compared to those with a smaller Q-angle. The researchers suggested that pelvic width to femoral length ratios, rather than Q-angle was a better structural predictor of knee valgus during dynamic movement.<sup>8,40</sup>

*Joint Laxity* Generalized joint laxity may potentially place the athlete at greater risk of ACL injury.<sup>8</sup> Investigators have demonstrated an increased risk of lower extremity injury among athletes with generalized joint laxity and knee hyperextension.<sup>41</sup> Specifically, anterior-posterior knee joint laxity is a risk factor for anterior cruciate ligament injury. It was reported that a 2.8 times greater risk of non-contact ACL injury in the United States Military Academy cadets with generalized joint laxity compared to normal joint laxity subjects.<sup>8,42</sup> It was also retrospectively observed that subjects with ACL injuries had greater generalized joint laxity in comparison to healthy age-matched controls.<sup>43</sup> In addition, the authors reported a 78.7% proportion of genu



recurvatum among ACL-injured subjects versus the 37% in the control group. Knee joint laxity could alter multi-planar, dynamic lower extremity motions and loads, placing ligaments to a higher risk of rupture.<sup>8</sup>

*ACL Size* The structural properties of the anterior cruciate ligament have been examined and studied as possible risk factors for ACL injury or rupture. Structural differences such as length, cross-sectional area, volume, mass, fibril concentration, stiffness, and elasticity may predispose an individual to injury.<sup>8</sup> ACL structural properties have been associated with gender differences. The ACLs in women are shorter and have less cross-sectional area, volume, and mass when compared with that of men. Lower fibril concentration and lower percent area occupied by collagen fibrils in females compared to males has also been reported.<sup>44</sup>

*ACL Notch Width* There is controversy regarding the size of the intercondylar notch and the association with ACL injury. Some studies have reported that a smaller intercondylar notch pose risk of ACL injury.<sup>8,45</sup> In addition, there have been reports of a significant relationship between the ACL cross-sectional area and the notch surface area.<sup>8</sup> The smaller the intercondylar notch the smaller the cross-sectional area of midsubstance ACL. It has been suggested that the ACL impinges at the anterior and posterior roof of the smaller notch during tibial external rotation and abduction.<sup>8,46</sup>

### ***Previous Injury***

Previous injury poses the greatest risk of injury. An injury can cause functional and mechanical instability, proprioceptive defects, impairments and imbalances in muscle strength, or persistent ligamentous laxity.<sup>47</sup> Research shows that re-injury occurs to the same or contralateral ACL in equal proportion. Similarly an ankle sprain poses a risk of a secondary sprain to the ipsilateral or contralateral ankle.<sup>31,48,49</sup> Pefanis et al,<sup>50</sup> found that a previous ankle

sprain was the most important predictor of a subsequent ankle sprain, with a 21% increase occurrence. Efforts to prevent injuries rather than treating them afterwards are gaining more momentum.

These risk factors are non-modifiable and therefore out of our control. It is important to identify non-modifiable risk factors in order to improve modifiable factors about that joint. For example, joint laxity cannot be corrected without an invasive surgery, however improving muscle strength and generalized joint stiffness to that affected joint may reduce its risk for injury. Muscle strength and joint stiffness are just two modifiable injury risk factors that can be altered to decrease injury risk.

### **Modifiable Injury Risk Factors**

Modifiable injury risk factors are characteristics or influences that can be changed. These risk factors include neuromuscular control and biomechanics, as well as the weather, type of playing surface, and type of shoe. These modifiable influences can be altered in order to decrease the risk of injury, for example by avoiding playing in dangerous weather or performing corrective rehabilitative exercises.

#### ***Neuromuscular***

In order to respond to an unanticipated perturbation, there must be an unconscious activation of the dynamic restraints surrounding a joint. This unconscious activation is referred to as neuromuscular control.<sup>8</sup> The neuromuscular system is responsible for generating movement, and therefore developing athletic actions. Poor or slow neuromuscular activation may pose a risk of lower extremity injury. Many studies<sup>51-54</sup> have been conducted regarding neuromuscular risk factors and the relationship to anterior cruciate ligament injuries. The studies examined the

effects of strength and muscle recruitment, joint stiffness and stability, and muscle fatigue on risk of injury.

*Co-Activation* Coordinated muscle action and co-activation is a critical component in protecting any joint from injury during dynamic movement. At the knee, the quadriceps and hamstrings are in an antagonist- agonist relationship, and provide dynamic stabilization.<sup>8,55</sup> A study of female soccer, basketball, and volleyball athletes during landing of the stop-jump task revealed increased quadriceps activation and decreased hamstring activation.<sup>56</sup> The contraction of the quadriceps creates an anterior shear of the tibia, without reciprocal activation of the hamstrings. This increase load stresses the ACL, and increases the risk of a non-contact ACL injury.<sup>56</sup> Weak hamstrings also increase ground reaction forces at the knee.<sup>57</sup> High ground reaction forces during landing indicate poor absorption of the force by the musculature. Therefore the joint and passive structures must compensate. When the hamstrings are incapable of absorbing these stresses, it places the ACL at a high risk of rupture. Therefore, having hamstring strength and control is vital to decreasing anterior shear forces and loading the ACL.

*Joint Stiffness* When the hamstrings and quadriceps co-contract the muscles provide stiffness to the knee, and protect ligaments from injury. The quadriceps and hamstrings provide anterior-posterior joint stiffness at the knee, protecting the cruciate ligaments. However, as previously mentioned, weak or poorly recruited lower extremity muscles create an unbalanced muscular pull, reducing joint stiffness.<sup>8</sup>

*Muscle Fatigue* Muscular fatigue has also been reported to be an injury risk factor. Muscular force development and contraction velocity is significantly reduced by muscle fatigue.<sup>54</sup> Fatigued muscles absorb less energy, thus transferring forces to passive tissues.<sup>54</sup> Fatigue adversely alters kinematics, neural feedback, joint stability, dynamic balance and control, which

are all associated with an increase risk of injury.<sup>54</sup> It has been shown, that under fatigue conditions, knee flexion angle decreased, and proximal tibial anterior shear force and knee varus moments increased when performing stop-jump tasks.<sup>58</sup> The decreased range of motion and increased shear force poses a risk of injury.

Other research comparing ACL injuries during the second half of competition to the first, not statistically different.<sup>59</sup> This suggests that muscular fatigue alone is not an isolated injury risk factor. In addition to muscular fatigue, unanticipated actions has been shown to directly impact ACL injury risk. Borotikar et al,<sup>60</sup> examined the effects of fatigue and decision-making on the lower extremity kinematics during sport related landings. During unanticipated landing with muscle fatigue, there was an increase hip extension and internal rotation at initial contact. As well in peak stance, there was an increase in knee abduction and internal rotation, and ankle supination angles. Additional research suggests that the effects of muscle fatigue and unanticipated decision-making poses the worst-case scenario for sustaining an ACL injury.<sup>61</sup>

### ***Role of Movement on Injury Risk***

Abnormal human movement may predispose an individual to injury. Caroline Finch wrote, “Injury has been defined as the failure of the body structure and/or tissue arising from the transfer of excess energy to those structures. In other words, injury at this fundamental level is a biomechanical phenomenon”<sup>62</sup>. To better analyze the biomechanical risk factors, the biomechanics of landing are broken down by joint.

#### ***Trunk***

Movement of the trunk in comparison to the lower extremity has been correlated to injuries of the low back and limbs. Zazulak et al,<sup>63</sup> investigated the correlation between trunk displacement and knee injury. They found that athletes who had sustained knee injuries had the

greatest displacement in every plane. Lateral trunk flexion was the strongest predictor of knee, ligament, and ACL injuries.<sup>63,64</sup> Trunk displacement, in combination with proprioception, and history of low back pain predicted knee ligament injury with 91% sensitivity and 68% specificity. This model predicts knee, ligament, and ACL injury risk in female athletes with a percent accuracy between 84 and 91.<sup>63</sup> The trunk or core plays an important role in stabilizing the lower extremity during activities, and should be included in an injury prevention program.<sup>65</sup>

### *Hip and Knee*

The relationship between the knee and hip joints is so intertwined, it is difficult to isolate their individual role on injury risk. Multiple studies have been conducted on female high school soccer, basketball, and volleyball athletes, during jump-landing tasks, in particular motions that occur at the hip and knee.<sup>56,66-68</sup> Females have less hip and knee flexion during landing preparation of a vertical stop-jump task.<sup>56</sup> This preparatory position for landing may result in increased ACL load, and a risk for non-contact ACL injury. On average, females exhibited a stiff landing posture. Females landed in a similar hip and knee flexion angles at the initial contact and maximum knee flexion. In other words, when the average female jumps and lands, their knees at maximum flexion are almost in the same position at initial contact. Therefore, they are not increasing their knee flexion angle after initial contact to help absorb the impact forces created from landing. A more erect posture at landing increases ground reaction forces, and may increase the risk of ligament injury.

Hewett et al,<sup>68</sup> female high school soccer, basketball, and volleyball athletes, indicated that ACL- injured subjects had increased knee abduction angle, 2.5 times greater knee abduction moment, and 20% higher ground reaction force compared to uninjured subjects. As well as increased greater knee abduction angles compared to their male counterparts. Another study

showed an increased external adduction moment about the hip at landing.<sup>69</sup> A greater hip adduction moment may place a greater valgus stress at the knee, suggesting that coronal plane motions at the hip creates knee abduction. Isolated hip adduction is not a risk factor for lower extremity injury, but when it causes knee adduction it is.<sup>68</sup> In preparation for landing from a stop-jump task, teenage female basketball, volleyball, and soccer athletes had less hip external rotation and increased knee internal rotation compared to males.<sup>56</sup> In addition, females exhibited a greater external adduction moment about the hip at landing.<sup>70</sup> During an unanticipated cutting maneuver, female high school soccer, basketball, and volleyball athletes were at increase risk of non-contact knee ligament injury due to an increased internal-external rotation moments applied to the knee.

### *Ankle*

The mechanics of the ankle joint, are crucial in altering ground force reactions and abnormal biomechanics in the entire kinetic chain. Restricted dorsiflexion of the ankle may contribute to an altered movement pattern. A loss of ankle dorsiflexion can restrict the forward progression of the tibia over the talus during simultaneous knee flexion and ankle dorsiflexion, as seen during squatting or walking up stairs. To compensate for the limited motion of the tibia, the subtalar joint may pronate, and therefore shift the tibia and the knee medially into greater valgus alignment.<sup>71</sup>

Multiple studies have examined restricted available dorsiflexion range of motion during landing. A study by Hagin et al,<sup>72</sup> reported greater knee-valgus displacement and posterior ground reaction forces when participants landed on an inclined surface, restricting available dorsiflexion, compared to a flat surface that permits full dorsiflexion displacement. Sigward et al,<sup>73</sup> reported that individuals with less passive dorsiflexion range of motion demonstrated greater

knee-valgus excursion during landing. Research conducted by Bell et al,<sup>74</sup> supports that dorsiflexion range of motion influences frontal-plane knee motion. This was demonstrated when a wedge was placed under the calcaneus, to increase available dorsiflexion range of motion, during a controlled squatting task.

In addition, landing with less available ankle dorsiflexion is linked with less hip and knee flexion.<sup>75</sup> This un-flexed lower extremity position increases the vertical ground reaction force at initial contact. A more plantarflexed position is more desirable because the position allows most shock absorption and reduces ground reaction forces.<sup>8,75</sup> The landing position that is linked to an increased risk of sustaining a non-contact ACL injury during competitive play is in an increase heel to flat foot loading mechanism.<sup>76</sup> Studies revealed that female basketball and soccer players had a greater maximum ankle eversion range of motion than males, during the stance phase of cutting.<sup>77</sup> This excessive eversion, with cutting, may increase the internal tibial rotation, knee valgus stress, anterior tibial translation, and load onto to the ACL during extension.<sup>8</sup>

These findings suggest that restricted dorsiflexion range of motion may increase ACL loading and injury risk, due to the association with less knee-flexion displacement, greater knee-valgus displacement, and greater ground reaction forces during landing.<sup>32</sup> Ankle mobility is a vital component to lower body movements, and limited mobility may be a predisposition to ankle re-injury or other lower extremity injuries.

### **Body Mass Index**

Some authors have postulated that a greater body mass index may result in a more erect lower extremity posture with decreased knee flexion upon landing.<sup>78</sup> A greater body mass index increases the risk for ACL injuries, especially among female adolescent soccer players, college

recreational athlete, and female army recruits.<sup>8,79</sup> However other authors found no impact of body mass index on ACL injuries in female athletes, including soccer players.<sup>80</sup>

## **Hormones**

There is conflicting evidence of the association of sex hormones and the incidence of ACL injury. One perspective is that hormonal factors are believed to play an important role for non-contact ACL injuries among female athletes. One conclusion is that female athletes might be more predisposed to ACL injuries during the pre-ovulatory phase of the menstrual cycle, which is consistent with the estrogen surge seen during this phase of the cycle.<sup>81</sup> However, not all hormonal studies used a control group nor stratified for oral versus non-oral contraceptive use.

Sex hormones have been associated with an increase in anterior knee laxity, less ACL tensile strength, and impaired neuromuscular function. Zazulak et al,<sup>82</sup> concluded that there is a significant effect of menstrual cycle phase on knee laxity. Other studies that evaluated the effect of oral contraceptives on knee laxity are conflicting. The use of oral contraceptives increased the dynamic stability of the female athlete's knee.<sup>83</sup> However, others have reported greater anterior tibial displacement in oral contraceptive users compared to those not using hormonal replacement therapy.<sup>84</sup> Further research is required to understand the influence of estrogen and other hormones on the tensile strength and biomechanical properties of ligaments. Sex hormones have been associated with changes in motor coordination, isokinetic strength, anaerobic and aerobic capacities, high intensity endurance, muscle relaxation time, and muscle fatigability in the females.<sup>85</sup>



## Environmental

Environmental injury risk factors are extrinsic or “outside of the body”, and to an extent out of our control. These include certain types of footwear and playing surface.

*Footwear* Footwear is a potential risk factor for ACL tears because it controls the fixation of the foot during the athletic activities. Studies have supported that the number, length, and cleat placement is associated with an increase risk of anterior cruciate ligament injury.<sup>8,86</sup> A prospective study evaluated the incidence of ACL injuries in American Football. The authors found a higher risk of ACL ruptures with footwear made of longer irregular cleats placed at the peripheral margin of the lateral sole with a number of smaller pointed cleats positioned medially. This cleat placement may have provided a higher torsional resistance compared to other types of cleats.<sup>86,87</sup> However, there are many confounding factors, such as, biomechanical, neuromuscular, hydration status, and others that need to be further investigated in footwear studies.

*Type of playing surface* The characteristics of the playing surface, regardless of weather conditions may influence ACL injury rates. Artificial surfaces are generally associated with higher shoe-surface traction than natural grass, therefore increasing the risk for ACL tears.<sup>8</sup> A recent prospective study by Meyers et al,<sup>88</sup> examined incidence, mechanisms, and severity of injuries of collegiate female soccer athletes on FieldTurf and on natural grass. They concluded FieldTurf had significantly less trauma when relating injury time loss, player position, injury grade, injuries under various field conditions and temperatures, cleat design, and turf age. Therefore FieldTurf is a practical alternative when comparing injuries in collegiate women’s soccer.<sup>88</sup>

## **Other**

Other extrinsic injury risk factors include level of competition, skill level, and external bracing or taping. The level of competition is considered an injury risk factor because of the evidence supporting that a greater number of injuries occur during a game or competition compared to a practice.<sup>47</sup> The level of skill an athlete possesses may also predispose the individual for injury. Studies have shown both that athletes in low and in high skill level groups are at increased risk of sustaining an injury while in competition.<sup>47</sup> High skill level participants appear to have an increase risk due to more exposure time and intensity of play. While low skill level players may seem to suffer from more injuries, but show a higher incidence rate based on less exposure time. External bracing and taping, especially for the ankle, has been shown to decrease the incidence of ankle ligamentous injury. Murphy et al,<sup>47</sup> reported that the use of ankle tape or braces increases the kinesthetic awareness of ankle positioning, and increases support to the ankle joint by limiting ankle inversion.

## **Gender Differences**

Injury rates and risk factors between the two sexes has been a consistent area of research, because there is evidence to suggest that women are at higher risk of sustaining a lower extremity injury compared to men. One of the most popular topics in this area, are the differences between ACL injury incidences. Early research supported that men have a higher absolute ACL injury rate than women, however when the injury rate is normalized to sports exposures women have a higher ACL injury rate in most sports.<sup>89</sup> In the 2013-2014 collegiate academic years, there were 271,055 males and 207,814 female student-athletes. Therefore men may sustain more ACL injuries, but compared to the population, women have a greater

proportional risk for sustaining an ACL injury. Recent research supports higher ACL injury rate amounts in women compared to men.<sup>1,52</sup> The NCAA Injury Surveillance System data have shown female-to-male ratio of ACL injuries of 3:1 in basketball and soccer, 4:1 in softball/baseball, and 1.4:1 in lacrosse.<sup>1</sup> Many studies have reported that female college athletes are at a 2 to 10-fold greater risk of noncontact ACL injuries, compared with male athletes playing the same sport.<sup>52,53,90,91</sup> Gray et al,<sup>91</sup> reported a 10-fold greater incidence of ACL injuries in professional female basketball players, whereas Malone et al,<sup>92</sup> showed a 6 to 8-fold higher rate in female collegiate basketball players. Among different collegiate divisions, the ACL injury rate was not different and was consistently greater for female student-athletes reported by the NCAA.<sup>90</sup>

These staggering injury statistics between men and women has prompted researchers to explore the possible reasons for these differences. Studies have identified lower extremity biomechanical differences during landing and cutting activities between male and female team sport athletes.<sup>93</sup> It has been reported that noncontact ACL injuries may be related to sagittal-plane mechanics in female athletes.<sup>92</sup> Females who land with decreased knee flexion may increase the forces on the ACL.<sup>90</sup> Chappell et al,<sup>94</sup> suggested that a decreased knee flexion angle in post-pubertal females may increase anterior knee shear at landing due to increased quadriceps force and decreased hamstring firing, which are associated with an increased risk of injury. Other authors have concluded that females have higher generalized joint laxity and anterior-posterior knee joint laxity than males, and therefore at greater risk for non-contact ACL injury.<sup>8,52</sup> One of the most regarded reasons for the disparity in injury rates is that women more frequently exhibit dynamic knee valgus compared to men. Dynamic knee valgus is the combination of decreased knee flexion, increased hip internal rotation and increase knee valgus loads.<sup>95</sup> These

neuromuscular differences between women and men place female athletes at higher risk of lower extremity injury. The increased risk of ACL injuries among women is likely multifactorial, and not due to a single structural, anatomical, or biomechanical feature.

There is also evidence to suggest that females are at higher risk for ankle sprains.<sup>22</sup> Women had a cumulative incidence rate of 13.6 per 1,000 exposures compared to their male counterparts of 6.94 per 1,000 exposures.<sup>22</sup> Continued research in the subject matter is required to further examine the ankle injury risk factors between men and women. The combined structural, anatomical, or biomechanical differences and statistical evidence supports that female collegiate athletes have a greater need for injury prevention interventions.

## **INJURY EPIDEMIOLOGY BY SPORT**

Athletes involved in basketball, soccer, and volleyball are constantly exposed to potentially damaging forces as they perform countless repetitions of these maneuvers in both practice and game situations.<sup>10</sup> Research supports that the tasks demanded in these sports may result in many different lower extremity injuries. Such maneuvers like performing a block in volleyball, a side step in basketball, or changing directions in soccer, are all risky movements that mimic non-contact anterior cruciate ligament or other lower extremity injury mechanisms.

### *Women's Basketball*

Basketball is a multifaceted and complex team game that combines movement with and without the ball. These movements include short sprints, abrupt stops, fast changes in direction, acceleration, different vertical jumps as well as hand movements such as dribbling, blocking, and passes. Successful playing performance depends on explosive strength and take-off power of the legs, strength of the arms and shoulder girdle, agility with and without the ball, coordination,

speed, shooting accuracy, and ball handling ability. Although basketball demands complicated upper and lower extremity movements, sixty percent of all injuries, recorded by the NCAA Injury Surveillance System, were to the lower extremity. Injuries to the lower extremity include chronic and acute injuries to the hip, thigh, knee, lower leg, ankle, and feet. The most commonly injured lower extremity joint, reported by the NCAA ISS, was to an ankle.<sup>21</sup> Approximately 25% of game injuries and 23.6% of practice injuries were to the ankle.<sup>21</sup> Published reports identified that 30% to 70% of ankle ligament injuries in basketball were recurrent.<sup>21</sup> Basketball players with a history of ankle injury are almost 5 times more likely to sustain another ankle injury as those without a previous history. Thus, female basketball athletes with a history of ankle injuries require preventive interventions to avoid recurrent ankle injuries.

Following ankle injuries, internal knee derangements, such as meniscus or ligamentous injuries, were the second most common injuries in women's basketball. Internal knee derangements accounted for 16% of game injuries, and 9.3% of practice injuries. More specifically, 8% of game injuries were ACL injuries. As previously stated, anterior cruciate or ACL injuries are particularly devastating injuries, that are typically associated with high financial burden and time loss from sport. Many efforts have been made to identify the risk factors associated with this tragic injury, more specifically the mechanism of a non-contact anterior cruciate ligament injury. Of the ACL injuries reported by the NCAA ISS, 64% were non-contact, 27% contact, and 8% from other non-player contact in women's basketball. During basketball, non-contact anterior cruciate ligament injuries occur most commonly during stopping, landing, and cutting maneuvers. Video analysis of ACL disruptions noted that most non-contact injuries occur with the knee close to extension during a sharp deceleration or landing maneuver. Olsen et al,<sup>96</sup> stated "the sequence of events leading to a right-sided ACL injury

included (i) the subject takes two steps with the ball and (ii) pushes off to prepare for a sidestep cutting at high speed.” A study by Xie et al,<sup>97</sup> examined the phases of a high speed sidestep cutting maneuver that puts basketball athletes at an increased risk for ACL injuries.

Ten healthy collegiate female basketball athletes were instructed to run two steps forward, plant the non-dominant leg on the third step, and then step with the dominant leg at a 90-degree angle at a speed of 2-3 m/s. A 90-degree angle step was evaluated because previous studies have examined 45 degree or 30-40 degree angles and the 90-degree sidestep is dangerous and frequently used in athletic events. Video analysis measured the knee flexion angle from the sagittal plane and the valgus and varus angles from the frontal plane during the sidestep cutting. In addition, bipolar superficial EMG sensors were used to measure the maximum voluntary isometric contraction against five seconds of manual resistance of the vastus lateral, vastus medial, biceps femoris, and semimembranous muscles on each subject’s non-dominant leg.<sup>97</sup> The sidestep cutting stance time was divided into stop and side-movement phases. The mean knee valgus angle peak during the stop phase was 11.7 degrees while during the side-movement phase the peak angle was 9.1 degrees. Three of the 10 subjects presented with only one knee valgus angle peak, measured at 19.5+/-10.3 degrees, which was 4.2-5.3 degrees greater than previously reported. Knee valgus has been recognized as a dominant risk factor for ACL injury. The possibility of ACL injuries may be increased during the stop phase because the knee valgus angles peaks during the stop phase and tend to be greater than those during the side-movement phase.<sup>97</sup> Xie et al,<sup>97</sup> concluded that in order to prevent ACL injuries in women’s basketball there is a need to train hamstring muscles and avoid knee valgus during the stop phase of a sidestep cutting maneuver.

Women's basketball demands highly skilled movements from the upper and lower extremities of its players. In addition, female basketball players must be proficient at handling a basketball while performing skilled movements. Women's basketball players may benefit from exercise-based injury prevention programs that focus on improving cutting maneuvers while handling a basketball.

### *Women's Soccer*

Soccer is the most commonly played sport in the world, with an estimated 265 million active soccer players participating in the sport as of 2006.<sup>8,98</sup> The popularity of women's soccer has increased remarkably in recent years, with an increase of 34% since 2000. As seen with any increase in participation rate is an increase incidence of injury. As reported by Dick et al,<sup>99</sup> in more than 20,000 games and 54,000 practices, 5,373 and 5,838 injuries were reported, respectively. Of those injuries, nearly 70% of all game and practice injuries were to the lower extremity. Most activities during a soccer game involve walking, jogging, and running. It has been documented that jumping and pivoting are frequently performed. For every 2 turns a soccer player performs during a game, a landing from a jump or header occurs.<sup>90</sup> These sport specific tasks mimic many lower extremity injury mechanisms, which is further supported by their corresponding lower extremity injury rates. The two most common lower extremity injuries in women's soccer are the ankle and knee joints. Ankle sprains account for 18.3% of soccer injuries. Soccer players are often resistant to prophylactic ankle braces or athletic taping during activity, therefore injury prevention programs are exceptionally important to implement when other intervention measures are underutilized.

Knee internal derangements are the second most common lower extremity injury in collegiate women's soccer, accounting for approximately 16% of lower body injuries. Knee

injuries in females are well-documented, specifically injuries to the anterior cruciate ligament. ACL injuries accounted for 6% in game situations, and 2% in practice. In soccer, female players are up to six times greater risk for sustaining an anterior cruciate ligament tear compared to their male counterparts. The disparity in injury rates has been attributed to biomechanical and neuromuscular differences between men and women. This is most evident when analyzing non-contact injury mechanisms. In collegiate women's soccer, 53% of ACL injuries that occurred in games, and 65% in practices, were non-contact injuries.<sup>99</sup> Non-contact ACL tears are when at the time of injury there is no physical contact with another player. Common playing scenarios precluding a non-contact ACL injury are maneuvers that involve a change of direction or cutting task. Cutting is an essential movement to either track the soccer ball, or to evade an opponent, unfortunately the likelihood of injury increases dramatically during such actions.<sup>100</sup>

A study by Cortes et al,<sup>100</sup> investigated the changes in lower limb kinetic and kinematic risk factors during a sidestep cut tasks and pivot tasks in female collegiate soccer athletes. Each task was studied with a rearfoot landing, and a forefoot landing. During a sidestep-cutting task with the rearfoot landing, participants landed with an erect posture. At initial foot contact using the rearfoot landing technique, there was decreased knee flexion, decreased knee internal adductor moment, and increased knee valgus and hip flexion. This type of task produced a lower peak vertical ground reaction force, and a decreased posterior ground reaction force at initial contact. In comparison to the rearfoot landing technique, the forefoot landing technique had greater knee flexion and hip flexion angles. During the pivot task a similar pattern was seen. The rearfoot landing technique had increased angles and forces, except for the knee sagittal and frontal plane moment. The rearfoot landing technique presented decreased knee valgus and flexion angles, knee adductor moment, and posterior ground reaction force, and an increased hip



flexion angle at initial contact. The rearfoot had increased hip flexion and decreased knee valgus angles over the forefoot landing technique. At peak stance, the rearfoot had increased hip flexion and decreased knee valgus angles over the forefoot landing technique.<sup>100</sup> Therefore landing in a rearfoot landing technique shows less risk of ACL injury factors.

The perceived kinematic and kinetic differences seen between landing techniques for each task suggest that the landing techniques present differentiated characteristics and that the injury mechanism may be dependent on the combination of foot landing technique and task utilized. Regardless of the landing technique used, all participants adopted a knee valgus position. The knee valgus position presented by the participants could increase their likelihood of injury as compared to participants that present neutral to varus alignment. Previous research supports that an increase in valgus angle and adduction loading is a strong predictor of ACL injuries. Therefore irrespective of the landing technique utilized by the female collegiate soccer players in this study, they may have an overall increased risk for injury due to this valgus position.<sup>100</sup>

### *Women's Volleyball*

According to Agel et al,<sup>101</sup> there were 2,216 injuries reported in more than 50,000 women's volleyball games, and 4,725 injuries from more than 90,000 volleyball practices. Although most of the skills performed by volleyball players, such as spiking, setting, serving, and blocking, demand repetitive overhead upper extremity movements, more than 55% of injuries were to the lower extremity. Lower extremity Injuries in volleyball most frequently occur to the ankle and knee joints. Ankle ligament sprains accounted for approximately 44% of game injuries, and 29% of practice injuries. Ankle ligament sprains most often occur when a player lands from an attack or a block, and comes in contact with another player's foot. The next

most common lower extremity injuries are internal knee derangements, which include injuries to the meniscus, cruciate or capsular ligaments. Internal knee derangements accounted for 14% of game injuries, and 8% of practice injuries. Within internal knee derangements, injuries most frequently occur to the meniscus (37.7%), then the collateral ligaments (33.6%), followed by the anterior cruciate ligament (26.3%), and the posterior cruciate ligament (2.3%). This data contradicts previous research on volleyball injuries, which reported that patellar tendinopathies, or jumper's knee, occur more frequently than internal knee derangements. The discrepancy in the literature may be due to differences in reporting methods. The NCAA ISS records only injuries that result in loss of time, while most overuse injuries may not result in time loss, therefore skewing the incidence rates of injuries.

Due to the high prevalence of lower extremity injuries in volleyball, it is important to understand risky movement patterns seen during play. The sport of volleyball consists of a combination of high ground reaction forces, rapid loading times, and the high frequency of jumping and landing.<sup>64</sup> The skill of blocking, when a player or players jump and extend their hands above and over the net to block an attack by the opponent is crucial to the team's success.<sup>102</sup> The typical landing pattern after a volleyball block is toe to heel, and is characterized by first peak (F1) and second peak (F2) in the vertical ground reaction force component. F2 occurs when the heel makes ground contact during the toe-heel landing. F1 happens just after the initial contact with the ground or during passive loading. It appears that during F1 is when an ACL injury is most likely to occur. Volleyball blocks can be characterized into two different patterns. The first is a successful block, the blocker completes the play and the ball lands on the opponent's side of the net after a block, and therefore the player is not subject to time pressure upon landing. Players usually use a 'stick' landing after a successful block. The stick landing

does not incorporate a subsequent move. The feet are relatively parallel at the time of ground contact and the player is able to stand upright without over-balance. The second is an unsuccessful block, the blocker attempts the block however the ball continues onto the blocker's side of the net, where it is then played for subsequent attacking move. Then the player is forced, upon landing, to step back away from the net prior to a subsequent attack move. Therefore players must react to the play, and they may not have sufficient time to land safely. A volleyball player may use a step-back landing technique after an unsuccessful block. This involves the player stepping back from the net immediately upon landing. The feet are relatively parallel at the time of ground contact, and the player steps backwards with a single leg immediately upon landing.<sup>64</sup> The step-back technique requires a greater VGRF, reduced knee energy absorption, and increased hip energy absorption in either their right or left leg. This technique also results in greater external rotation and valgus knee moments in both lower extremities compared to the stick technique. Increasing initial single leg knee flexion during step-back landing may assist with decreasing vertical ground reaction forces during a step-back landing.<sup>64</sup>

In both successful and unsuccessful blocks the volleyball player must quickly perform demanding movement patterns. When these tasks are hastily performed, high and unnatural forces may be placed at each joint of the lower extremity. Frequent hard landings with large impact forces may be a risk for knee injury, particularly ACL tears. Volleyball athletes may benefit from changes in landing technique, in efforts to prevent acute and chronic lower extremity injuries.

### *Sports Comparison*

These three sports require similar dynamic maneuvers, such as cutting, jumping, and landing in addition to their unique skill sets. These dynamic maneuvers have been regarded as

high-risk activities for injuring the ACL.<sup>66,67</sup> The sport of women's basketball involves vertical jumps and landings as well as short sprints, abrupt changes in directions, while handling a basketball. During these movements athletes may experience increased medial knee displacement. A study by Munro et al,<sup>95</sup> supported this claim, that 41 female basketball players from national league club teams exhibited a greater frontal plane projection angle, or dynamic knee valgus, compared to female soccer players during a single leg landing task. Another study by Herrington et al,<sup>67</sup> revealed that division 1 female basketball players exhibited a greater right knee valgus angle compared to women's volleyball players. Injury prevention interventions should include proper landing techniques, landing with increased hip and knee flexion, ankle mobility, and knee and hip musculature strengthening to decrease medial knee displacement.

Similar to women's basketball, women's volleyball consists of a high frequency of jumping and landing all while spiking, setting, passing, and blocking a volleyball. Due to the fast pace nature of the sport, athlete's must jump and land quickly to be successful. One study revealed that women's volleyball players had significantly greater knee valgus than basketball players during a unilateral step-landing task.<sup>67</sup> Injury prevention measures should focus on proper landing techniques, balance, and knee and hip musculature strengthening to decrease medial knee displacement.

Women's soccer athletes are similar to basketball athletes in that they must sprint, stop abruptly, and cut to avoid defenders. The sport of women's soccer continues to grow in popularity and competitive demands. Female soccer athletes must repeatedly sprint and change directions with and without the ball while avoiding an opposing player. One study examined cutting tasks in collegiate women soccer players after a prolonged activity trial, and demonstrated less hip and less knee flexion when cutting.<sup>103</sup> This finding suggests that a

women's soccer team may benefit from an injury prevention program that includes exercises to improve landing techniques, balance, and dynamic knee stability.

Specializing injury prevention programs to fit the needs of an individual sport or team may reduce injury incidence, injury risk, as well as improve performance. Identifying the injury risk factors between sports may assist in development of such programs.

## **INJURY RISK SCREENING TOOLS AND INJURY PREVENTION PROGRAMS**

Exercise-based injury prevention programs can reduce overall risk and severity of lower extremity injury.<sup>104</sup> Previous research suggests that exercise-based injury prevention programs are effective at reducing ACL and lower extremity injury risk and incidence as well as enhance performance.<sup>105,106</sup> Successful injury prevention programs may be developed based on screening methods that identify injury risk factors.

### **Screening Tools**

Utilizing screening tools to accurately identify biomechanical and neuromuscular injury risk factors may be a vital component in injury prevention. When screening tools are used before the season, the information collected may be used to identify athletes that are at high risk of developing an injury.<sup>107</sup> Additionally, this information may be used to develop a prevention program for the individual athlete, team, or sport. There are a number of different screening tools available that have been found to be useful in identifying injury risk factors.

The Landing Error Scoring System (LESS) is a reliable clinical screening tool that evaluates landing biomechanics associated with a jump-landing task to identify individuals at increased risk of suffering a noncontact ACL injury. Poor landing patterns during the jump-

landing task has previously been shown to be associated with an increased risk of knee ligament injury.<sup>66,108</sup> The jump-landing task requires the participants to jump from a 30-cm-high box onto the ground with both feet at a distance approximately half their height, and then immediately jump as high as they can, while two standard video cameras record the frontal plane and sagittal plane view. The LESS assesses lower extremity and trunk positioning at the point of initial contact with the ground, maximum flexion, and global fluidity and range of motion when landing from a jump-landing task through analysis of frontal and sagittal plane video data.<sup>109,110</sup> A higher LESS score indicates poor technique in landing from a jump and a corresponding increased risk of sustaining a lower extremity injury, while a lower score indicates better jump-landing technique.

Multiple studies have been conducted on or using The Landing Error Scoring System. One of the most important findings is that the LESS can successfully distinguish between groups on a range of jump-landing biomechanics that have previously shown to be related to ACL loading and injury mechanisms.<sup>109</sup> The LESS is a valid and reliable tool for identifying landing errors in multiple planes, and demonstrates good interrater and intrarater reliability.<sup>109</sup> However, the LESS may require the use of two video cameras and time to later review the testing. Studies have been shown to support that the Landing Error Scoring System-Real Time (LESS-RT) is a comparable method of screening.<sup>111</sup> The LESS-RT is a modified scoring and testing assessment developed to score jump-landing movement patterns in real time. The LESS-RT evaluates 10 jump-landing characteristics over 4 trials of the jump-landing task.<sup>111</sup> A study by Padua et al,<sup>111</sup> concluded that the LESS-RT is a quick, easy, and reliable clinical assessment tool that may be used to identify individuals with lower extremity injuries.

The Star Excursion Balance Test, SEBT, is a valid, reliable, clinical scale, for assessing static postural control. The SEBT is a series of single-limb squats using the nonstance limb to reach maximal distance to touch a point along 1 of 8 designated lines on the ground.<sup>112</sup> The participant's reach performance, in particular directions, indicates reduced joint motions that may contribute to decreased dynamic postural-control. Anterior reaching distance is strongly correlated to ankle dorsiflexion range of motion.<sup>112</sup> Knee flexion range of motion is most greatly associated with the anteromedial reach.<sup>112</sup> This method has been used repeatedly in research and clinical applications to differentiate the level of dynamics postural-control among individuals with various lower extremity injuries, including injuries to the ankle and knee.

A second movement-screening tool is the Functional Movement Screen (FMS), which is designed to easily identify restrictions or alteration in normal movements. The FMS consists of seven movement tasks; a deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability. A study by Gribble et al,<sup>112</sup> performed a study to determine if compensatory movement patterns predispose female collegiate athletes to injury, and if the Functional Movement Screening Tool (FMS) can be used to predict injuries in that population. The researchers found a lower score on the FMS was significantly associated with injury, with 69% of those scoring 14 or less sustaining an injury, and experiencing a 4-fold increase in injury risk. Thus supporting that the Functional Movement Screening Tool is an effective method of assessing biomechanical and neuromuscular injury risk factors.

### **Injury Prevention Programs**

The foundation of successful prevention programs utilizes exercises aimed on correcting modifiable neuromuscular risk factors by improving lower extremity movement patterns,

flexibility, strength, and balance.<sup>113</sup> Several studies have supported that prevention-training programs have improved biomechanical and neuromuscular characteristics during movement patterns, such as jumping, landing, and cutting maneuvers.<sup>114,115</sup> By improving lower extremity movement patterns through injury prevention programs there have been positive correlations to reduce injury incidence, decrease time lost from injury, as well as improvement in sport performance.<sup>114-116</sup> Despite the overwhelming advantages to implementing injury prevention programs, they are still not widely accepted. The largest barriers to program implementation are time and lack of sport specificity.<sup>116</sup>

#### *Decrease Injury Risk*

The purpose of any injury prevention intervention is to correct the modifiable injury risk factors. By correcting dangerous movement patterns that have been previously associated with lower extremity injury, athletes may experience a decrease in their risk of injury.

A study completed by Padua et al,<sup>114</sup> examined the retention of movement pattern changes after a 3-month and 9 month lower extremity injury prevention program. The Landing Error Scoring System was used to evaluate the participant's lower body movement patterns at pre-test, post-test, and 3 months after ceasing the training program. The results showed that the participants in both groups had improved from pre-test to post-test. However the participants within the 9-month training program, as known as the extended-duration training program, retained their improvements 3 months after ceasing the training program. This suggests that lower extremity injury prevention programs can improve movement patterns, and longer training duration may facilitate movement retention.<sup>114</sup> Numerous studies have investigated the Santa Monica Prevent Injury Enhance Performance Program (PEP) and its effect on movement patterns. The study supports that low intensity neuromuscular training programs can have a



positive effect on lower extremity biomechanics in athletic tasks and this lowers the risk for ACL injury.<sup>115</sup> The program was designed to be an alternative to a warm-up and consists of stretching, strengthening, plyometric, and sport-specific agility exercises.

The concept of improved movement patterns and reduced injury risk is positive, however this may not be enough to encourage athletes, coaches, and parents to use injury prevention programs. Therefore it is important to show that injury prevention programs not only reduce risk of injury, but also have been proven to reduce injury rates and time loss from injury.

#### *Reduce Injury Rate and Time Loss*

The ultimate goal of an injury prevention program is to prevent injuries. Several studies have concluded that injury prevention programs reduce the incidence of injury and the time loss associated with an injury.

A review of twelve studies identified that female athletes who performed a given neuromuscular training program have a decreased risk of 73.4% to suffer a non-contact ACL injury compared with those who did not perform neuromuscular training. In order to successfully reduce the risk of ACL injury, it has been suggested that there must be a high compliance rate. Specifically, the overall compliance rate (attendance x completion) must be more than 66%.<sup>5</sup> A study by Kiani et al,<sup>5</sup> demonstrated a compliance rate greater than 66%, and reduced ACL injury incidence. Over an 8-month study, the intervention group did not observe any ACL injuries, while the control group had 5 non-contact ACL injuries.

A study on the F-MARC 11+ program showed reduced lower extremity injuries and decreased time lost with implementation of supervised injury prevention program. Forty-one NCAA Division III male collegiate soccer players from the same team participated in a training intervention for two seasons. The first season the team served as a control, while the following

season the team underwent the training intervention. The intervention team demonstrated a lower extremity injury and decrease time loss due to injury. During the control season, the team lost 291 days to injury, while in the intervention team season the team lost only 52 days to injury. The effect size of the intervention program to reduce days lost to lower extremity injury was 0.733, indicating a medium to large effect.<sup>104</sup> The overall injury risk decreased as well as the severity of those injuries decreased as shown by decreased time lost due to injury.<sup>104</sup>

At the collegiate level, a study by Gilchrist et al,<sup>117</sup> concluded that an injury prevention program is effective in preventing ACL injuries in female collegiate division 1 soccer athletes. Sixty-one division 1 women's soccer teams were randomly assigned to intervention or control groups. The intervention group was asked to complete the PEP three times a week throughout their competitive season. The most substantial findings were when comparing ACL injury rates between the two groups. Seven ACL injuries were reports in the intervention group compared with 18 in the control group. Although this finding was statistically insignificant, it is important to report there was a 41% lower ACL injury rate in the intervention group than the control group. The results of the study suggest that the PEP Program of neuromuscular and proprioceptive training is effective in preventing ACL injuries in female collegiate division 1 soccer athletes. The program can be accomplished during regular practice time without the need for additional special equipment or training. This evidence supports that there is time and use for injury prevention programs in a collegiate setting.

Injury prevention programs can effectively prevent injury and decrease the time loss associated with injuries, however some coaches and athletes are more likely to use an injury prevention program if they can see an increase in sport performance.<sup>5</sup>

### *Enhance Performance*

The most basic purpose of warming up and practicing is to prepare the athlete or team to compete, and win. To do so the team must prepare to perform better than the other team.

Substituting effective injury prevention programs as the team's practice and game warm-up must incorporate methods to improve athletic performance in addition to reducing injury risk, injury incidence, and time loss from injuries. Researchers have resorted to quantifying performance improvement through functional tests, such as balance and agility exercises.

A study by Filipa et al,<sup>106</sup> examined pre and post-test Star Excursion Balance Test (SEBT) composite scores between two groups of female soccer players. One group underwent an 8-week neuromuscular training program, while the other served as a control. At post test, the intervention group improved performance of the SEBT composite score on both limbs after 8 weeks of training, while no change was observed in the control group. The SEBT is a functional screening tool that assesses lower extremity dynamic stability and identifies athletes at high risk for lower extremity injury. Therefore, this tool may be useful to assess the efficacy of training programs designed to reduce injury risk and athletic performance, related to balance.

Another study used the SEBT in addition to single-leg balance, triple hop, and jumping-over-a-bar test to quantify performance.<sup>105</sup> Steffen et al,<sup>105</sup> recruited 29 youth female soccer teams, and randomized teams into one of two interventions groups or a control group. All groups performed the FIFA 11+ warm up program, for one competitive season, with different levels of instruction. The results reported significant differences in mean performance changes between the comprehensive, player-focused intervention group, and the control group. Single-leg balance and anterior direction of the SEBT improved more in the comprehensive and player-focused

group compared to the control group. The positive effects of this injury prevention program on performance, related to balance, are important for the acceptance and adoption of the program.

Injury prevention programs have the potential to improve athletic performance as well as prevent injuries. However, research is limited on measures of quantifying improved athletic performance. Future research should focus on improved quantifiable measures of athletic performance to create more acceptance and adherence to injury prevention programs.

### *Barriers*

Despite the growing understanding of the incidence of lower extremity injuries and the risk factors associated with them, implementing effective injury prevention programs continues to be a challenge.<sup>116</sup> A major challenge is creating administrative buy-in and support. Poor administrative or coach support may decrease injury prevention program compliance.

Compliance rates indicate how many athletes and how often the assigned injury intervention program is completed. Injury Prevention Programs with low to moderate compliance rates had higher risk of sustaining an ACL injury compared to programs with high compliance rates.<sup>5</sup> Some reasons why coaches may be unsupportive of implementing injury prevention program are the length of time of the program session, duration of the program over the sport season, and the non-sport specific exercise selection.

There has been success in the military setting, when certain steps within the prevention program's design and implementation are followed. Padua et al,<sup>116</sup> established a guideline to improve the injury prevention program compliance. One step involved developing administrative buy-in and support to ensure their commitment to implementing the injury prevention program. It is important to stress the positive effects a prevention program may have on both the individual and organization's success to the key stakeholders. Next, create an interdisciplinary

implementation team to identify and suggest possible solutions for all potential logistical issues that could negatively influence the adoption of the injury prevention program. The interdisciplinary implementation team should then identify logistical barriers and develop solutions to those barriers. Padua et al,<sup>116</sup> identified four main categories that impede program implementation, those are time, personnel, environment, and organization. Researchers within this study addressed each category by identifying the program's goals and using the best evidence based exercises to achieve those goals. This study noted that adopting preexisting injury prevention programs may results in suboptimal compliance. They stressed the importance of collaborating with key stakeholders to develop a good rapport, as well as create a custom injury prevention program, including a set of exercises that meet the organization, sport, or team's needs.

Although there are many positive aspects to injury prevention programs, implementation is still not widely accepted. Research efforts may benefit by focusing on developing more sport or team-specific injury prevention programs based on accurate screening methods.

## **CONCLUSION**

Female athletes are at a disadvantage. They are at higher risk of sustaining lower body injuries such as, recurrent ankle sprains and devastating ACL tears compared to their male counterparts.<sup>1,10,77,118</sup> Luckily, exercised- based injury prevention programs can effectively reduce lower body injuries and improve modifiable injury risk factors.<sup>5,114,117</sup> It is unclear whether athletes of different sports exhibit different movement errors and injury risk factors. In addition, restricted ankle dorsiflexion has been hypothesized to influence several movement errors<sup>32,119</sup> but this potential relationship has been scarcely studied in a female collegiate athlete

population. Ankle dorsiflexion can be easily measured<sup>119</sup> and modified through an injury prevention program. By understanding this information, athletic trainers may improve the efficiency of injury prevention programs to address the specific issues of each sport. In doing so, injury prevention programs may become more time efficient and sport specific.

## CHAPTER 2: Introduction

Sport-related injuries are common at the collegiate level. There is an estimated injury every two games or one injury every five practices for a team of 50 participants.<sup>1</sup> More than 50% of these reported injuries were to the lower extremity, with a majority occurring at the knee and ankle.<sup>1</sup> Individuals suffering from an injury suffer time lost from activity, functional limitations, a high risk of sustaining a subsequent injury, and the early development of osteoarthritis. Studies have reported that female college athletes are at a 2-fold to 10-fold greater risk of noncontact anterior cruciate ligament (ACL) injuries, compared with male athletes playing the same sport.<sup>52,53,90,91</sup> Therefore, adopting proactive injury prevention measures is an attractive alternative to the consequences associated with a lower body injury.

Exercise-based injury prevention programs performed as a sport warm-up can reduce lower extremity injury rates.<sup>5,104</sup> These programs utilize a variety of strengthening, balance, flexibility, and plyometric exercises aimed at improving neuromuscular control and movement patterns. Athletes that demonstrate poor movement technique during sport related tasks, such as landing and cutting, are at a higher risk for sustaining a lower body injury.<sup>5,109,120</sup> Specific examples of these poor movements include decreased sagittal plane joint flexion of the trunk, hip, and knee in combination with medial knee displacement and leg rotation.<sup>109</sup> A combination of exercises and instruction may be required to correct these movement patterns in order to teach athletes how to control their body and ensure sufficient muscle strength and joint motion is available. For example, one poor movement, medial knee displacement has been associated with less ankle dorsiflexion range of motion.<sup>119</sup>

The effectiveness of an injury prevention program depends on the compliance of the participants.<sup>121</sup> A major barrier preventing compliance is the time required to complete a

program.<sup>121</sup> Sugimoto et al,<sup>7</sup> determined that neuromuscular training programs aimed to prevent ACL injuries required 15-20 minutes to complete, which coaches feel is too long, especially in season.<sup>7</sup> An injury prevention program that is customized to improve neuromuscular deficiencies, identified in a team may improve both the efficiency and effectiveness of the program.

Customizing injury prevention programs to an entire team based on identified neuromuscular control deficiencies may be an externally valid approach since teams often complete the programs together prior to sport activity. Sport demands, especially in collegiate sports, may result in common deficiencies across a team and allow for customization to occur at a team level. Therefore, the purpose of this study was to study differences in movement technique in female collegiate basketball, soccer, and volleyball teams. A secondary purpose was to investigate whether injury history and ankle mobility influence movement technique, and need to be considered in injury prevention program implementation. We hypothesized that differences between sports would exist in movement technique. We also hypothesized that previous injury history would influence movement technique suggesting that programs should target these high-risk individuals. Finally, we hypothesized that restricted ankle range of motion would have a negative effect on movement technique.



## CHAPTER 3: Methods

### *Participants*

Forty-five division I collegiate, female, basketball, soccer, and volleyball athletes were asked to participate in this study. Participants with an injury or illness that prevented them from participating in physical activity at the time of testing were excluded from the study. The university's Institutional Review Board approved the study, and written informed consent was obtained from all participants.

### *Procedures*

Participants completed a single test session and a questionnaire to evaluate their history of sport participation and injuries. Height and mass were measured using a stadiometer and scale, respectively, at the beginning of the test session. Participants then completed ankle range of motion evaluations and a lower extremity movement assessment in the same order. The ankle range of motion evaluations consisted of three ankle dorsiflexion range of motion techniques, (1) Non-Weight Bearing in Knee Extension with Goniometer (2) Non-Weight Bearing in Knee Flexion with Goniometer and (3) Weight Bearing Lunge Test. A single rater collected all ankle range of motion measurements. The movement assessment consisted of a jump-landing task, which was scored on a later date using the Landing Error Scoring System (LESS).

### *Ankle Dorsiflexion Range of Motion*

*Non-Weight Bearing in Knee Extension with Goniometer (NWB-KE)* First, the subject was positioned lying supine on a treatment table, with their shoes off, while ankle dorsiflexion range of motion of each ankle was measured with the knee fully extended. The examiner plantarflexed the subject's ankle with their knee fully extended, and then the ankle was passively dorsiflexed until the point of first resistance. The angle between the shaft of the fibula and the

lateral midline of foot was measured with a standard goniometer. This measurement was repeated two times and then repeated on the other ankle.

*Non-weight Bearing in Knee Flexion with Goniometer (NWB-KF)* While the subject was positioned supine on a treatment table, with their shoes off, their knee was flexed to 30 degrees using a foam roller positioned under the distal femur. The examiner plantarflexed the ankle and then passively dorsiflexed until the point of first resistance. The angle between the shaft of the fibula and the lateral midline of foot was measured with a standard goniometer. This process was repeated twice, and then repeated on the other ankle.

*Weight Bearing Lunge Test (WBL)* Next, participants were positioned standing, facing a wall. The subject's test foot was positioned perpendicular to the wall with second toe and midline of the heel placed directly on a piece of guide tape on the floor. Participants were instructed to lunge forward, by directing their knee toward the wall until they reached maximum ankle dorsiflexion. Maximum ankle dorsiflexion was defined as the point right before the heel lifted off the ground. If the knee made contact the wall, the foot was repositioned further from the wall until the maximum range of dorsiflexion was achieved. The examiner then placed a digital inclinometer distal to the tibial tuberosity, in order to measure the angle of the tibia relative to the vertical plane with the heel in contact with the ground. The test was performed three times, and then repeated on the other ankle.

#### *Movement Assessment*

*Jump-Landing Task* Participants performed five jump-landing tasks from a 30 cm high box. The participants were instructed to jump forward a distance of 50% of their height, and then immediately perform a vertical jump for maximum possible height. Subjects did not receive any feedback or coaching on jumping or landing technique. Participants were permitted to practice

the jump-landing tasks as many as need to perform the task successfully. A successful jump is defined as the participants (1) jumps off from the bow with both feet, (2) jumps forward to reach the target area, not vertically, (3) lands with both feet in the target area, and (4) completes the task in a fluid motion.

Two standard video cameras (Canon FS400, Canon U.S.A. Inc., Lake Success, NY, USA) recorded the sagittal and frontal plane views of each participant completing the jump-landing task. These videos analyzed at a later time using the Landing Error Scoring System (LESS) by a single rater blinded to sport. The LESS is a clinical assessment tool of lower extremity movement patterns, and is valid and reliable in evaluating poor lower extremity biomechanics (Table 1).<sup>109</sup> The total LESS scores for each trial were averaged into one composite score per participant. Also, the presence or absence of individual LESS items were calculated and further evaluated.

Table 1: Operational Definitions for Individual Landing Error Scoring System Items

Landing Error Scoring System Items	Operational Definition of Error	Scoring
Knee flexion: initial contact	The knee is flexed less than 30° at initial contact	0= Absent 1= Present
Hip flexion: initial contact	The thigh is in line with the trunk at initial contact	0= Absent 1= Present
Trunk flexion: initial contact	The trunk is vertical or extended on the hips at initial contact	0= Absent 1= Present
Ankle-plantar flexion: initial contact	The foot lands heel to toe or with a flat foot at initial contact	0= Absent 1= Present
Asymmetrical Foot Contact	One foot lands heel to toe and the other foot lands toe to heel.	0= Absent 1= Present
Asymmetrical Timing	One foot lands before the other foot.	0= Absent 1= Present
Asymmetrical Heel-Toe/ Toe-Heel	One foot lands flat/ heel-toe and other foot lands toe-heel.	0= Absent 1= Present
Medial knee position: initial contact	The center of the patella is medial to the midfoot at initial contact.	0= Absent 1= Present
Lateral-trunk flexion: initial contact	The midline of the trunk is flexed to the left or right side of the body at initial contact.	0= Absent 1= Present

Stance width: wide	The feet are positioned greater than a shoulder width apart (acromion processes) at initial contact.	0= Absent 1= Present
Stance width: narrow	The feet are positioned less than a shoulder width apart (acromion processes) at initial contact.	0= Absent 1= Present
Foot position: external rotation	The foot is externally rotated more than 30° between initial contact and maximum knee flexion.	0= Absent 1= Present
Foot position: internal rotation	The foot is internally rotated more than 30° between initial contact and maximum knee flexion.	0= Absent 1= Present
Knee-flexion displacement	The knee flexes less than 45° between initial contact and maximum knee flexion.	0= Absent 1= Present
Hip-flexion displacement	The thigh does not flex more on the trunk between initial contact and maximum knee flexion.	0= Absent 1= Present
Trunk-flexion displacement	The trunk does not flex between initial contact and maximum knee flexion.	0= Absent 1= Present
Excessive trunk flexion displacement	The trunk flexes past parallel with the lower legs.	0= Absent 1= Present
Medial-knee displacement	At the point of maximum medial knee position, the center of the patella is medial to the foot.	0= Absent 1= Present
Asymmetrical loading	A weight shift is present.	0= Absent 1= Present
Wobble	The knee wobbles and demonstrates a quick varus/ valgus motion.	0= Absent 1= Present
Joint displacement	Soft: the participant demonstrates a large amount of trunk, hip, and knee displacement. Average: the participant had some, but not a large amount of trunk, hip, and knee displacement. Stiff: the participant goes through very little, if any, trunk, hip, and knee displacement.	0= Soft 1= Average 2= Stiff
Overall impression	Excellent: the participant displays a soft landing with no frontal-plane or transverse-plane motion. Poor: the participant displays large frontal-plane or transverse-plane, or the participant displays a stiff landing with some frontal-plane or transverse plane motion. Average: all other landings.	0=Excellent 1=Average 2= Poor

### *Data Analyses*

Separate one-way between-subjects analysis of variance (ANOVA) were performed to evaluate if differences existed in LESS composite scores and ankle dorsiflexion range of motion (ROM) (Right and Left: NWB-KE, NWB-KF, WBL) between sports. To further identify if specific items on the LESS differed between teams, chi-square tests were performed for each LESS error. Participants were coded as having an error if they demonstrated the error in at least 2 out of the 3 jump-landing trials. Separate one-way ANOVAs were also used to determine if history of ankle sprain or previous history of ACL injury affected LESS score or ankle dorsiflexion ROM.

Participants were classified as high risk if they had a LESS composite score of 5 or greater.<sup>110</sup> Those with a 4 or lower LESS score were considered low risk.<sup>110</sup> A one-way between subjects ANOVA was performed to determine if ankle dorsiflexion ROM influenced risk classification based on the LESS. Further, participants were classified as having restricted NWB ankle dorsiflexion ROM if they had less than or equal to 5°.<sup>119</sup> Participants were classified as having restricted WB ankle dorsiflexion ROM if they had less than or equal to 43°. Separate one-way between subjects ANOVA were performed to determine if the presence of restricted ankle dorsiflexion ROM in either WB or NWB measurements affect LESS score. We evaluated the 95% confidence interval of the mean difference for each pairwise comparison in the presence of an overall significant difference between groups. All data were analyzed using an a priori alpha level of 0.05 using SPSS (version 21.0, SPSS Inc, Chicago, Illinois).

## CHAPTER 4: Results

Forty-five collegiate female athletes volunteered to participate in this study (age= $20 \pm 2$  years, mass= $68.7 \pm 11.1$ kg, height= $171.6 \pm 9.4$ cm)(Table 2). We did not observe a significant difference between sports for the composite LESS score ( $P > 0.05$ ). However, basketball participants had less WBL motion than soccer participants ( $P=0.049$ ) (Table 3 & Figure 1). A greater proportion of basketball participants exhibited the “knee flexion at initial contact” error than the two other sports ( $P=0.043$ ) (Table 4). A greater proportion of soccer participants demonstrated the “asymmetrical contact” ( $P=0.058$ ) error than the other sports (Table 4).

There were no significant differences between ankle previous injury history and LESS score or ankle ROM ( $P > 0.05$ ) (Table 5). Participants with less than five degrees of non-weight bearing ankle range of motion in knee flexion (NWB-KF) had significantly higher LESS scores ( $P=0.001$ ) (Table 6). Participants in the “High Risk” group ( $LESS \geq 5$ ) had less range of motion as measured by Right NWB-KE ( $P=0.01$ ), Left NWB-KE ( $P=0.01$ ), Right NWB-KF ( $P=0.03$ ), and Left NWB-KF ( $P=0.003$ ) (Table 8). Participants who exhibited LESS error “Medial Knee Displacement” had significantly less Left NWB-KF ( $P=0.02$ ), and Right WBL Test ( $P=0.04$ ) (Table 9).

Table 2: Participant Demographics

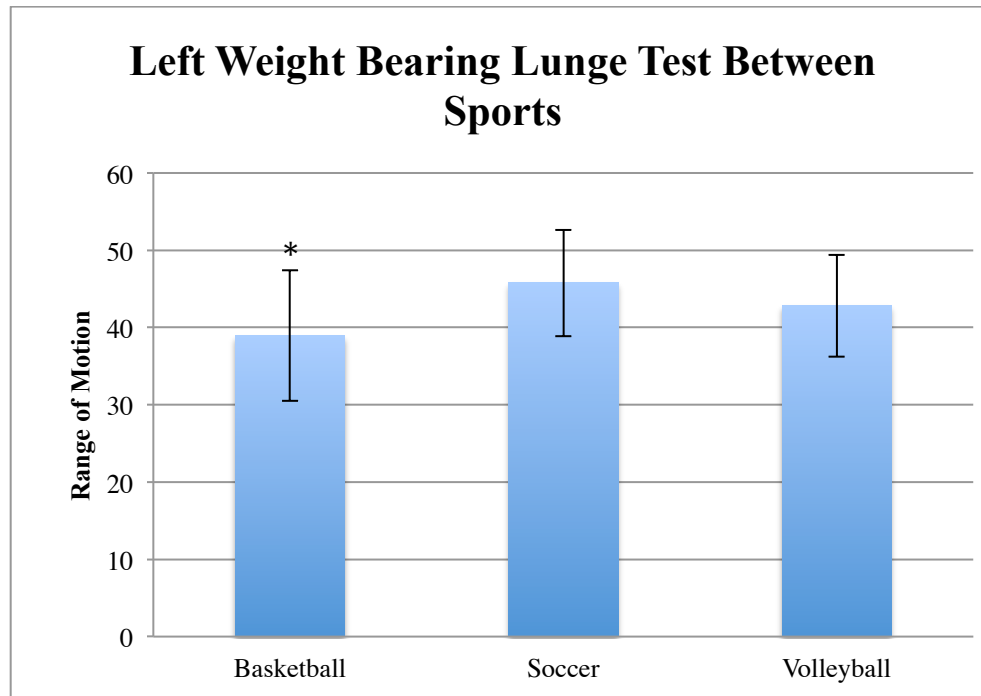
Sport	N	% Team	Age (years)	Height (cm)	Mass (kg)	Number Participants with Previous ACL Injuries	Number Participants with Previous Ankle Sprains
Basketball	11	92%	$20 \pm 2$	$179.2 \pm 9.1$	$76.7 \pm 14.3$	2	7
Soccer	21	80%	$20 \pm 2$	$165.3 \pm 4.9$	$64.3 \pm 7.2$	3	14
Volleyball	13	87%	$20 \pm 2$	$175.7 \pm 9.0$	$69.1 \pm 10.1$	1	10

Table 3: Mean Ankle Range of Motion Variables and Average LESS Score Differences Between Sports

Variable	Sport	Mean $\pm$ SD	95% Confidence Interval	P Value
Right Non-Weight Bearing in Knee Extension (Right NWB-KF)	Basketball	7.36 $\pm$ 3.49	(5.02, 9.71)	.98
	Soccer	7.63 $\pm$ 5.41	(5.17, 10.10)	
	Volleyball	7.38 $\pm$ 4.99	(4.36, 10.41)	
Left Non-Weight Bearing in Knee Extension (Left NWB-KF)	Basketball	6.53 $\pm$ 3.57	(4.12, 8.93)	.76
	Soccer	6.29 $\pm$ 5.13	(3.95, 8.62)	
	Volleyball	7.48 $\pm$ 4.42	(4.82, 10.16)	
Right Non-Weight Bearing in Knee Flexion (Right NWB-KE)	Basketball	7.93 $\pm$ 5.66	(4.14, 11.74)	.90
	Soccer	7.87 $\pm$ 4.97	(5.61, 10.14)	
	Volleyball	8.77 $\pm$ 6.94	(4.58, 12.96)	
Left Non-Weight Bearing in Knee Flexion (Left NWB-KF)	Basketball	7.55 $\pm$ 4.05	(4.8, 10.27)	.92
	Soccer	7.89 $\pm$ 5.78	(5.26, 10.52)	
	Volleyball	8.49 $\pm$ 7.13	(4.18, 12.80)	
Right Weight Bearing Lunge Test (Right WBL)	Basketball	40.50 $\pm$ 6.20	(36.34, 44.66)	.12
	Soccer	45.57 $\pm$ 7.01	(42.38, 48.76)	
	Volleyball	43.72 $\pm$ 5.64	(40.31, 47.12)	
Left Weight Bearing Lunge Test (Left WBL)	Basketball *	38.96 $\pm$ 8.46	(33.27, 44.64)	.049
	Soccer	45.77 $\pm$ 6.89	(42.38, 48.76)	
	Volleyball	42.80 $\pm$ 6.57	(38.83, 46.77)	
Average LESS	Basketball	4.79 $\pm$ 1.81	(3.58, 6.00)	.65
	Soccer	5.60 $\pm$ 2.46	(4.48, 6.72)	
	Volleyball	5.41 $\pm$ 2.64	(3.82, 7.00)	

\* Statistically significant between groups at  $P < 0.05$ .

Figure 1: Left WBL Differences Between Sports



\* Statistically significant between groups at  $P < 0.05$ .



Table 4: LESS Item Differences Between Sports

Variable	Sport	Number of Participants With and Without Error		Pearson Chi-Square
		0=Absent	1= Present	
Knee flexion: initial contact	Basketball*	8	3	0.04
	Soccer	20	1	
	Volleyball	13	0	
Hip flexion: initial contact	Basketball	11	0	>0.05
	Soccer	21	0	
	Volleyball	13	0	
Trunk flexion: initial contact	Basketball	11	0	0.56
	Soccer	20	1	
	Volleyball	13	0	
Ankle-plantar flexion: initial contact	Basketball	11	0	0.57
	Soccer	20	1	
	Volleyball	13	0	
Asymmetrical foot contact: initial contact	Basketball	11	0	0.05
	Soccer*	13	8	
	Volleyball	10	3	
Asymmetrical timing: initial contact	Basketball	11	0	0.40
	Soccer	18	3	
	Volleyball	12	1	
Asymmetrical heel-toe/ toe-heel	Basketball	11	0	> 0.05
	Soccer	21	0	
	Volleyball	13	0	
Lateral-trunk flexion: initial contact	Basketball	9	2	0.14
	Soccer	21	0	
	Volleyball	11	2	
Medial knee position: initial contact	Basketball	10	1	0.07
	Soccer	21	0	
	Volleyball	10	3	
Stance width: wide	Basketball	7	4	0.18
	Soccer	19	2	
	Volleyball	10	3	
Stance width: narrow	Basketball	10	1	0.12
	Soccer	12	9	
	Volleyball	10	3	
Foot position: external rotation	Basketball	5	6	0.73
	Soccer	11	10	

	Volleyball	8	5	
Foot position: internal rotation	Basketball	11	0	0.56
	Soccer	20	1	
	Volleyball	13	0	
Knee-flexion displacement	Basketball	11	0	>0.05
	Soccer	21	0	
	Volleyball	13	0	
Hip-flexion displacement	Basketball	11	0	>0.05
	Soccer	21	0	
	Volleyball	13	0	
Trunk-flexion displacement	Basketball	11	0	>0.05
	Soccer	21	0	
	Volleyball	13	0	
Excessive trunk-flexion displacement	Basketball	8	3	0.76
	Soccer	17	4	
	Volleyball	11	2	
Medial-knee displacement	Basketball	4	7	0.89
	Soccer	9	12	
	Volleyball	6	7	
Asymmetrical Loading	Basketball	4	7	0.75
	Soccer	5	16	
	Volleyball	4	9	
Wobble	Basketball	6	5	0.82
	Soccer	9	12	
	Volleyball	6	7	
Joint displacement	Basketball	8	3	0.51
	Soccer	15	6	
	Volleyball	7	6	
Overall Impression	Basketball	8	3	0.17
	Soccer	8	13	
	Volleyball	7	6	

\* Statistically significant between groups at  $P < 0.05$ .

Table 5: Mean Ankle Range of Motion Variables & Average LESS Score in Participants with and without Previous ACL or Ankle Injuries

Variable	Injury (0= No, 1= Yes)	Mean $\pm$ SD	95% Confidence Interval	P Value
Right Non-Weight Bearing Ankle ROM in Knee Extension	0	7.29 $\pm$ 4.81	(5.73, 8.85)	.50
	1	8.83 $\pm$ 4.83	(3.76, 13.91)	
Left Non-Weight Bearing Ankle ROM in Knee Extension	0	6.60 $\pm$ 4.81	(5.04, 8.16)	.74
	1	7.28 $\pm$ 1.85	(5.33, 9.22)	
Right Non-Weight Bearing Ankle ROM in Knee Flexion	0	8.13 $\pm$ 5.88	(6.22, 10.03)	.95
	1	8.28 $\pm$ 4.12	(3.95, 12.60)	
Left Non-Weight Bearing Ankle ROM in Knee Flexion	0	8.00 $\pm$ 5.99	(6.06, 9.94)	.95
	1	7.83 $\pm$ 4.10	(3.53, 12.14)	
Right Weight Bearing Lunge Test	0	43.51 $\pm$ 6.34	(41.46, 45.57)	.47
	1	45.64 $\pm$ 8.72	(36.49, 54.80)	
Left Weight Bearing Lunge Test	0	42.78 $\pm$ 7.38	(40.39, 45.18)	.30
	1	46.24 $\pm$ 8.83	(36.97, 55.52)	
Average LESS	0	5.55 $\pm$ 2.11	(4.86, 6.23)	.15
	1	4.05 $\pm$ 3.52	(.36, 7.74)	

Table 6: Comparative LESS Score in Participants with and without Restricted Left NWB in Knee Flexion Ankle Range of Motion

Left NWB in Knee Flexion Ankle Range of Motion *	N=45	Mean $\pm$ SD	95% Confidence Interval	P Value
Restricted <5	31	4.62 $\pm$ 2.22	(3.81, 5.44)	.001
Not Restricted >5	14	6.95 $\pm$ 1.78	(5.92, 7.80)	

\* Statistically significant between groups at P < 0.05.

Table 7: High or Low Injury Risk Count by Sport

Sport	High or Low Injury Risk	
	High	Low
Basketball	4	7
Soccer	11	10
Volleyball	7	6
Total	22	23

Table 8: Ankle Range of Motion by High or Low Injury Risk

Variable	High or Low Injury Risk	Mean $\pm$ SD	95% Confidence Interval	P Value
Right Non-Weight Bearing Ankle ROM in Knee Extension *	Low	9.18 $\pm$ 4.11	(7.41, 10.96)	.014
	High	5.73 $\pm$ 4.89	(3.56, 7.89)	
Left Non-Weight Bearing Ankle ROM in Knee Extension *	Low	8.34 $\pm$ 4.67	(6.32, 10.36)	.011
	High	4.96 $\pm$ 3.73	(3.32, 6.62)	
Right Non-Weight Bearing Ankle ROM in Knee Flexion *	Low	9.97 $\pm$ 6.22	(7.26, 12.66)	.025
	High	6.24 $\pm$ 4.32	(4.32, 8.16)	
Left Non-Weight Bearing Ankle ROM in Knee Flexion *	Low	10.38 $\pm$ 5.41	(8.04, 12.72)	.003
	High	5.47 $\pm$ 5.03	(3.24, 7.70)	
Right Weight Bearing Lunge Test	Low	45.49 $\pm$ 6.26	(42.78, 48.20)	.08
	High	42.03 $\pm$ 6.68	(39.06, 44.99)	
Left Weight Bearing Lunge Test	Low	45.18 $\pm$ 8.21	(41.62, 48.73)	.08
	High	41.23 $\pm$ 6.41	(38.39, 44.07)	

\* Statistically significant between groups at  $P < 0.05$ .

Table 9: Medial Knee Displacement by Ankle Range of Motion

Variable	Medial Knee Displacement (0=Absent 1=Present)	Mean $\pm$ SD	95% Confidence Interval	P Value
Right Non-Weight Bearing Ankle ROM in Knee Extension	0	8.58 $\pm$ 3.84	(6.73, 10.43)	.20
	1	6.71 $\pm$ 5.31	(4.56, 8.85)	
Left Non-Weight Bearing Ankle ROM in Knee Extension	0	7.93 $\pm$ 3.60	(6.20, 9.66)	.12
	1	5.79 $\pm$ 4.97	(3.78, 7.79)	
Right Non-Weight Bearing Ankle ROM in Knee Flexion	0	9.53 $\pm$ 5.58	(6.84, 12.22)	.16
	1	7.14 $\pm$ 5.57	(4.90, 9.39)	
Left Non-Weight Bearing Ankle ROM in Knee Flexion *	0	10.33 $\pm$ 5.82	(7.53, 13.14)	.017
	1	6.26 $\pm$ 5.12	(4.19, 8.33)	
Right Weight Bearing Lunge Test *	0	46.17 $\pm$ 6.73	(42.93, 49.41)	.039
	1	42.06 $\pm$ 6.11	(39.60, 44.53)	
Left Weight Bearing Lunge Test *	0	45.73 $\pm$ 7.80	(41.97, 49.49)	.059
	1	41.43 $\pm$ 7.00	(38.60, 44.26)	

\* Statistically significant between groups at  $P < 0.05$ .

## CHAPTER 5: Discussion

Injury prevention programs performed as a warm-up prior to sport reduce injury rates,<sup>114,115</sup> but are not frequently adopted in high-risk sports, such as female intercollegiate basketball, soccer and volleyball. The time required to complete an injury prevention program is a commonly reported barrier to widespread implementation.<sup>5,116</sup> Current injury prevention program implementation follows a general “one size fits all” program for all sports. However, this approach may lead to the inclusion of unnecessary exercises resulting in programs requiring more time than needed leading to poor adoption and compliance. Therefore, the overall purpose of this study was to identify sport differences as possible ways to modify injury prevention programs to reduce the time demand for collegiate female athletes.

We evaluated whether differences in movement technique and ankle mobility exist between entire sport teams, since all members of a team typically perform injury prevention programs. While small differences existed between sports, our results indicate that injury prevention programs for women’s basketball, soccer and volleyball should not vary drastically in exercise inclusion. Injury prevention programs can be improved and made more sport specific with the inclusion of sport specific tasks, such as the addition of a dribbling a basketball. However, we did observe that restricted ankle motion impaired movement in all athletes, which indicates injury prevention programs should include exercises to improve ankle motion. These findings are promising because a general injury prevention program can be successful despite the type of sport and improving ankle mobility in these athletes may improve outcomes.

This is the first study to evaluate lower extremity biomechanics and ankle range of motion between three different division-I collegiate female sports. Other studies have investigated different populations, such as males<sup>71</sup> or adolescents<sup>110</sup>, or only lower extremity

biomechanics<sup>68</sup>, or ankle range of motion.<sup>119</sup> However, there is limited research comparing injury risk profiles between sports or teams. There are potential differences between sports due to the different sport-specific skills and physical demands. The sport of women's basketball involves vertical jumps, landing, short sprints, and abrupt changes in directions while handling a basketball. While female soccer athletes must repeatedly sprint and change directions with and without the ball while avoiding an opposing player. Cutting is an essential movement to either track the soccer ball, or to evade an opponent, unfortunately the likelihood of injury increases dramatically during such actions.<sup>100</sup> Women's volleyball consists of a high frequency of jumping and landing all while spiking, setting, passing, and blocking a volleyball. Injuries to the ACL and ankle occur across all three sports at different extents, suggesting that there are different movement risks driving these injury occurrences.

The main purpose of this study was to determine whether specific jump-landing movement errors (LESS) differed between Division I women's basketball, women's soccer, and women's volleyball student-athletes. We found that there were significant differences in regards to two individual LESS movement errors between sports. A greater proportion of women's basketball athletes had the "knee flexion initial contact" error compared to women's soccer and volleyball athletes. This suggests that this team of women's basketball athletes land in an erect posture following a jump. Landing in an erect posture increases the forces at the joint, and may increase the risk of injury. Other studies have described similar findings in regards to landing postures.<sup>8,56</sup> This finding doesn't necessitate a need to refine current injury prevention programs, but supports their continued implementation.

A greater proportion of women's soccer athletes had "asymmetrical contact" errors compared to women's basketball and volleyball athletes. Asymmetrical contact indicates side-to-

side differences in lower-extremity kinetic loading and force generation.<sup>122</sup> Although many high-level soccer athletes are proficient in these skills bilaterally, they may still experience leg dominance and asymmetries. Paterno et al,<sup>122</sup> studied limb asymmetries in post ACL reconstructive athletes, and concluded that the noninvolved limb encountered increased forces at a faster rate during the landing phase of a drop-vertical jump test. The combination of increased vertical ground reaction force loading over a shorter period of time may be a greater risk for ACL injury. Leg asymmetries may be predictive of ACL injuries in young healthy females athletes.<sup>66</sup> This finding supports the continued need for exercise-based injury prevention programs in this population, but not necessarily the need to change an existing injury prevention program to focus on this landing error alone.

Surprisingly, previous ACL or ankle injury history did not impair movement technique, as measured by the LESS. A previous injury is considered the greatest risk factor for future injury secondary to changes along the kinetic chain.<sup>123-125</sup> Six participants reported a previous ACL injury and reconstruction during their lifetime. ACL injuries have been linked to successive ACL injury, concomitant injuries, and premature OA.<sup>6,7</sup> Thirty-one participants reported suffering from an ankle sprain within the past five years. An ankle sprain poses risk of a secondary sprain of the ipsilateral or contralateral ankle among active adults.<sup>31,48-50</sup> Therefore it was unanticipated that previous injury was not associated with a higher LESS score. This finding suggests that athletes with previous injury history do not need to be targeted for additional injury prevention measures. All athletes, despite previous injury history, can complete the same injury prevention program.

A very positive finding of this study is athletes with previous ACL injury had better LESS scores compared to athletes without a previous ACL injury. The mean LESS score for

those six individuals was  $4.05 \pm 3.52$ , which is considered a low injury risk value. While the participants without an ACL injury had a mean score of  $5.55 \pm 2.11$ , which is a high injury risk value. Although the results were not statistically significant we observed an effect size of  $r=0.6$ , which is considered a large effect. This discovery contradicts a previous study by Bell et al.<sup>126</sup> They reported that individuals with an ACL reconstruction exhibited higher total LESS score than healthy uninjured controls. The total LESS score was greater in the ACLR group by an average of 1.1 errors, or 16% greater.<sup>126</sup> There are a few possible explanations for our findings. A limitation to our finding is that we only had six participants with a previous ACL injury within our population. The participants with a previous ACL injury may have had low risk but still suffered an injury. Or the participants who underwent ACL reconstruction may have also been undergoing continued maintenance rehabilitation or preventive intervention, and therefore may have better movement pattern retention than other individuals with previous ACL reconstructions. Further research may be warranted to investigate movement pattern retention in female athletes within their college careers and years later.

We did not observe any clinically significant differences between sports in movement technique. A limitation to this study is that it is specific to a collegiate female population within one university. Therefore it appears that sport related differences are inconsequential in terms of implementing injury prevention programs. Injury prevention programs have been proven to effectively reduce injury incidence, decrease injury risk, and enhance performance.<sup>114-117</sup> To improve program acceptance and compliance, a simple modification to an existing exercise can be made more sport specific with the addition of a ball or a sport specific movement.

The secondary purpose of this study was to examine ankle range of motion and lower body movement patterns, in-between and within sports. Our results indicated that between



sports, left WBL test yielded significant results ( $P > .05$ ,  $P = .049$ ). Forty-four out of forty-five participants indicated that they were right leg dominant, when asked what leg they would use to kick a soccer ball for maximum distance. Women's basketball athletes measured a significantly lower left, or non-dominant, weight-bearing lunge ( $38.96 \pm 8.46$ ), compared to women's soccer ( $45.77 \pm 6.89$ ) and volleyball ( $42.80 \pm 6.57$ ) groups. This indicates that women's basketball athletes exhibited restricted left ankle dorsiflexion during the weight-bearing lunge test. The weight-bearing lunge test was used to replicate a squatting or jump-landing task. The results would indicate that the basketball athletes may exhibit less left ankle dorsiflexion during sport specific tasks that include landing. This finding may be correlated to our early finding, a greater proportion of women's basketball athletes exhibited with "knee flexion initial contact" error. This new finding suggests that women's basketball athletes may be landing in a more erect posture due to decreased left weight bearing ankle dorsiflexion range of motion.

Regardless of sport, 31 out of the 45 participants presented with restricted left non-weight bearing ankle dorsiflexion range of motion while in knee flexion. Restricted ankle range of motion was defined as less than or equal to five degrees in a non-weight bearing position, and less than or equal to 43 degrees during the weight bearing lunge. Dill et al,<sup>119</sup> previously defined the range of motion criteria that was used in our study. Restricted ankle dorsiflexion range of motion could be a result of restricted arthro-kinematics or muscle tightness. When the participants were stratified by restricted or not restricted ankle range of motion in the L NWB-KF, there was a significant association between restricted ankle range of motion and higher composite LESS scores. No other ankle ranges of motion differences were found. This finding indicates that female basketball, soccer, and volleyball student-athletes with less left ankle

dorsiflexion with knee flexion present with poorer lower extremity movement patterns, and may be at greater risk for injury.

This finding is further supported when participants were stratified by High or Low LESS score. Previous literature has identified a cutoff point of 5, as having optimal screening properties: 86% sensitivity and 71% specificity, for greater risk of sustaining noncontact ACL injury compared to counterparts with LESS scores below 5.<sup>110</sup> Participants with a High LESS score, of 5 or greater, had decreases in all non-weight bearing range of motion measurements. Therefore athletes with restricted passive ankle dorsiflexion may be at a greater risk for sustaining an ACL injury. Ankle dorsiflexion range of motion has been previously associated with landing biomechanics and ACL injury risk factors.<sup>32</sup> Restricted dorsiflexion during landings results in greater peak landing forces, less knee-flexion and hip-flexion displacement, and greater medial knee displacement and moment.<sup>32,66</sup> It is interesting to note that we did not find any significant association between the WBL tests and LESS scores. The WBL tests were used to replicate the available range of motion during a squat or jump-landing task. While the non-weight bearing measurements in knee extension assesses the extensibility of both gastrocnemius and soleus muscles, whereas the measurements in 30° of knee flexion isolate the extensibility of the soleus. This may suggest that our participants have less passive ankle dorsiflexion due to muscular tightness. Fong et al,<sup>32</sup> argued that the extended-knee test position was a better indication of the dorsiflexion ROM restrictions, because the gastrocnemius contributes considerably to the force attenuation during the landing task. However, they did not find differences between a flexed-knee dorsiflexion range of motion, and concluded that there is no correlation between the flexed-knee dorsiflexion ROM and landing biomechanics. Our findings suggest an association between the flexed-knee dorsiflexion ROM and higher LESS

scores. Efforts to improve gastrocnemius and soleus flexibility should be considered in an injury prevention program.

Medial knee displacement (MKD) is a LESS item error that has previously correlated to poor knee kinematics and decrease ankle dorsiflexion. Our findings and many other studies support this claim.<sup>73,95</sup> MKD is when the center of the patella moves medially and crosses over a line extending upward from the great toe during a squatting maneuver. Excessive MKD is associated with strength and flexibility deficits of the hip and ankle joint musculature.<sup>74</sup> Sigward et al,<sup>73</sup> reported a negative correlation between ankle dorsiflexion and frontal plane knee excursion. This correlation indicates that individual with less dorsiflexion range of motion had greater amounts of frontal plane knee excursion during the drop land task. Our participants who exhibited the LESS error “Medial Knee Displacement” had significantly decreased Left NWB-KF ( $P=0.017$ ), Right WBL ( $P=0.039$ ), and Left WBL ( $P=0.059$ ). Decreased WBL test indicates reduced ankle range of motion during squatting and landing, therefore to compensate for their restricted mobility, these individuals may compensate by medially displacing their knee. It is interesting that our participants with MDK also had significantly decreased left NWB-KF range of motion. This may suggest that our participants’ left soleus is tighter than their right, and may contribute to poor movement patterns. All but one participant reported right side leg dominance, therefore we may assume that our participants are experiencing muscle tightness on their non-dominant limb. Inclusion of bilateral ankle mobility exercises should be in an injury prevention program.

## **Conclusion**

Our results suggest that a proportion of female collegiate athletes exhibit high risk of lower extremity injury and less than average ankle dorsiflexion. Future research should include a larger sample size and investigate other sports and sex. The findings support a significant relationship between restricted ankle range of motion and lower body movement patterns, as measured by the Landing Error Scoring System (LESS). This supports the need and importance for ankle mobility exercises. Future research should investigate the cause of non-weight bearing and weight bearing restricted ankle dorsiflexion range of motion, and if injury prevention programs are effective in improving ankle dorsiflexion range of motion.

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