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A Comparison of Landing Styles in Men's and Women's Division III Volleyball Players Using the Landing Error Scoring System, Gluteus Medius Strength, Navicular Drop Test, and Hip Flexor Tightness

Kedryn Orrison
Health and Physical Education & Psychology
North Central College
30 N. Brainard St.
Naperville, Illinois 60540 USA

Faculty Advisor: Kendall Selsky, MS, ACT, CSCS, NASM-PES; Dr. Karl Kelley

Abstract

Previous research has shown that noncontact anterior cruciate ligament (ACL) injuries can occur as a result of jumping tasks due to errors in landing position, and various anatomic factors. The current study attempts to determine if there is a correlation between the Landing Error Scoring System (LESS and selected measures of lower extremity kinetics and kinematics in collegiate volleyball players. The kinetic and kinematic measures being studied are gluteus medius muscle strength, FISS line/navicular drop test, and the Thomas test for hip flexor tightness. Results found that in women, right gluteus medius strength (0.20), and hip flexor tightness at the knee (0.21) best predict a higher LESS score. In males, total positive categories (0.55), and gluteus medius strength (Right 0.47; Left 0.31) best predict a higher LESS score. These results can be useful in designing effective jump training injury prevention programs.

Keywords: ACL, LESS, Injury

1. Mechanism of ACL Injury

Anterior cruciate ligaments are injured with a force that causes an anterior displacement of the tibia, which can occur from both contact and non-contact injuries. Contact injuries occur when a blow drives the tibia anterior relative to the femur or the femur posteriorly relative to the tibia. Approximately 60% of ACL injuries are result of non-contact mechanisms, and the rate is elevated to 70% for females[19]. These non-contact injuries include rotational injuries or a hyperextension of the knee. ACL injuries resulting from a rotational force usually involve injury to other ligaments or structures and typically occur with multi-planar knee motion when at or near full extension, in hyperextension, and usually while weight-bearing[36].There are different types of non-contact ACL injuries, not only the typically seen plant and twist mechanism. Knee valgus can also be a factor in ACL injuries. The associated internal or external rotation of the tibia can cause increased stress on the ACL during weight bearing transitions[29]. This knee valgus motion or position is seen in many cutting and landing motions which may lead to an increased number of ACL injuries. This can be the traditional cutting motion, jump stop, or an improper landing from a jump. The current study will focus on non-contact ACL injuries because these may be prevented as opposed to ACL injuries due to a contact mechanism.

2. Epidemiology

Every year, there are more than 200,000 anterior cruciate ligament (ACL) injuries. Since about 60-70% are caused by a non-contact mechanism, a discussion has been on going about how to prevent these injuries[18,19]. While males have the highest total number of ACL injuries, females are at an even greater risk of injury due to intrinsic and extrinsic factors[18]. This study focuses on the college male and female volleyball athletes and how non-contact ACL injuries can be screened with three factors and jump landing mechanics to possibly decrease the likelihood of non-contact ACL injuries.

Some studies have found that the risk of ACL injury increases with the level of competition[4, 14,17]. Beynnon et al. found that injury rates were lowest with junior varsity athletes and would increase through varsity and college athletes[4]. This same discrepancy in injury rates is also seen between Division I and Division III institutions, with the former with significantly higher rates[14]. While it has been shown that injury rates increase as the level of competition increases, the same is seen between practices and games. The greatest number of injuries are seen in games as opposed to practices, even with the larger volume of practices[14, 17].

. College athletes are at a higher risk than high school athletes. There are differences in the likelihood of ACL injury between sports. Soccer has one of the highest ACL injury rates[4] and skiing was the most likely mechanism of injury for an isolated ACL injury[9]. Some studies have found that positional difference can also increase the incidence of ACL injuries. Backs and ball carriers in rugby are at higher risks for ACL injuries due to the unpredictability of impact while being tackled[16]. Other studies have found that female intercollegiate rugby player have a 5.3 times higher incidence of ACL injuries in s as compared to males[33, 22]. Females are at a higher risk of injury than male athletes, between 2-8 times more likely to suffer an ACL tear[18].

3. Risk Factors

3.1 Anatomic Risk Factors

Anatomic risk factors are important to identify because of the increased risk to the ACL. There are typically no methods for altering these risk factors. A narrow intercondylar notch has been associated with a high risk of ACL injury. This increases risk of injury because the ACL is typically smaller and weaker than a normal ACL due to the lack of joint space where the ACL resides[40, 42]. Joint laxity[40, 42] and increased pelvis widths[18, 42] females were also found to increase risk of ACL injuries. Other anatomic factors include a decrease in depth of concavity of the medial tibial plateau and an increase in the posterior-inferior-directed slope of the tibial plateau[40]. Anterior pelvic tilt[42] and hamstring flexibility[18] may also play a role in anatomic injury predisposition

Hewett et al. found that there are four neuromuscular imbalances that increase risk of ACL injuries in females: ligament dominance, quadriceps dominance, leg dominance, and trunk dominance[11]. The two that refer to anatomical risk factors are ligament dominance and quadriceps dominance. Ligament dominance occurs when muscles do not sufficiently absorb the ground reaction forces (GRF), so the joint and ligaments absorb the high amounts of force. These are not designed for the increased amounts of force and lead to higher injury rates. The muscles of the lower extremity and posterior chain are most efficient at absorbing GRFs. Posterior chain is comprised of the gluteus maximus, gluteus medius, hamstrings, gastrocnemius, and the soleus. This group of muscles is used to absorb the large GRFs so that the force is not transmitted to the knee joint or ligaments. A large majority of athletes lack enough strength in their posterior chain and suffer from quadriceps dominance. This occurs when the quadriceps muscle is used to primarily stabilize the knee joint causing an anterior shear stress on the tibia which stresses the ACL. Since females typically land in more knee extension than males, the posterior chain, primarily the hamstrings, are not being utilized to control the tibia from moving posteriorly and stressing of the ACL[11].

3.2 Environmental Risk Factors

Environmental risk factors cannot be altered through training but do show areas where there is increased risk for ACL tears. The shoe-surface interface may have an effect on ACL injuries[42]. According to Dragoo, Braun, and Harris, NCAA football players experienced a higher ACL injury rate while playing on artificial (1.73 per 10,000) as compared to natural grass (1.24 per 10,000)[7]. There is some evidence that suggests that more ACL injuries occur on a dry field than on a wet field (95.2% 58 of 61 athletes)[35]. Drier surfaces can allow the foot to remain planted while the rest of the leg and body twists causing an ACL tear. On a wet playing surface, the foot would lack adequate friction to remain fixed to the ground. A study of NFL players found that the colder the temperature, the lower ACL injury rates were[30].

3.3 Hormonal Risk Factors

In addition to environmental risk factors, the internal hormonal environment can affect injury risk. There appears to be a higher incidence rate of ACL injury during the early and late follicular phases of the menstrual cycle[40]. Slauterbeck et al. found that more ACL injuries occurred during days one and two of the follicular phase[39]. There is conflicting evidence regarding whether or not females experience changes in ligament laxity during different phases of their menstrual cycles[2,37].

3.4 Mechanical Risk Factors

Mechanical risk factors are typically associated with how the athlete moves. These can be anatomically based or biomechanically related. Pronation[18, 42] and limb alignment, such as genu valgum, genu recurvatum, and an anteverted femur[42], can predispose athletes to injury due to the increased stress associated with these biomechanics. Pronation occurs when adduction and plantar flexion of the talus and eversion of the calcaneus occur when weight bearing. Typically, these feet present as pes planus or flattened medial longitudinal arch. Pronation is specifically addressed in the current study due to the compensation that can occur up the kinetic chain[41]. Genu recurvatum occurs when the knee has more than five degrees of hyperextension. These people present as standing with their knees "locked" in an extreme extended position. Genu valgum is an angulation of the femur and tibia where the knees are visibly closer together. Typically this is referred to as "knock-kneed." Genu valgum can be congenital or due to excessive foot pronation[41].This leg position puts increased strain on the ACL and during jump mechanics will increase the risk of tearing.

Due to leg dominance imbalances, females experience larger differences in recruitment patterns, muscle strength, and muscle flexibility. However when females tear their ACL, all or most of their weight is on one leg. The differences between dominate and non-dominate legs are significant enough to cause dysfunction and possible injury. Trunk dominance and control of trunk motion is important for controlling GRFs. Loss of trunk control in three dimensional space could be related to growth and maturation factors[11].

Certain sport specific body motions such as landing from a jump and cutting maneuvers, put the body in a position where the ACL is highly stressed[42]. These are motions that are commonly the cause of ACL injuries. Muscle strength, muscle fatigue, muscular activation and coordination differ between males and females, as well as between ACL injured and non-ACL injured athletes[40, 42]. Muscle imbalances can alter normal joint mechanics, and alter compressive or tensile forces placed on the joint which can increase injury risk[41].

3.5 Errors In Landing Mechanics

More non-contact ACL injuries occur during unilateral landings. Landing mechanics play a big role in injury risk. Ireland, Willson, Ballantyne, and Davis found that gluteus medius and maximus weakness affect joint loading patterns and lower extremity control[15]. This weakness in hip internal rotation and adduction can lead to dynamic knee valgus during landing[6]. Active trunk flexion during landing caused an increase in knee and hip flexion during landing[5]. An increased knee abduction angle at landing, increased knee abduction movement, longer stance time, and increased ground reaction force were noted as predictors in female athletes[12]. During a stop jump task, females have a higher injury ratio rate than males (0.0480 vs 0.0097). Factors that contributed to injury include decreased knee flexion angles, posteriorly tilted tibia condyle angles, hamstring and gastrocnemius forces, and center of pressure to angle joint distance[23]

Athletes that have previously sustained an ACL injury are at an increased risk due to differences in landing strategy. Paterno et al. showed that there are leg imbalances when landing upon return to sport. The leg with previous ACL injury had a lower peak VGRF compared to the contralateral limb[32]. This compensatory landing strategy could cause another injury[11].

4. Screening for Risk of ACL Injuries

In order to screen athletes for their risk of ACL injury, the Landing Error Scoring System (LESS) was developed at the University of North Carolina by a consortium of researchers and medical professionals under the direction of Dr. Darin A. Padua[31]. The LESS is used to determine biomechanical risk during landing mechanics. This test evaluates 17 errors related to landing position that are associated with increased ACL loading. Scores can range from 0-22. A lower score indicates fewer landing errors present according to the LESS[31]. Females typically have a higher score than males, and there are gender differences in mechanics. Typically females have less hip and knee flexion at initial contact, increased knee valgus with a wide stance, and decreased knee-flexion displacement. Males are more likely to toe out, land heels first, and land with an asymmetrical foot position[3].

Due to existing research, the hypothesis for this study is that positive navicular drop, weak gluteus medius, and hip flexor tightness will correlate to a higher LESS score in both men and women, but with a larger effect in the women.

5. Methodology

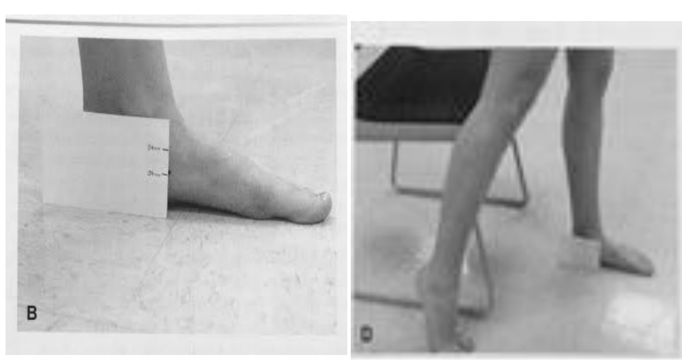
5.1 Participants

Study design was approved by an internal Research Ethics Committee. Aftwer which, subjects were recruited from a convenience sample of collegiate volleyball players. The female subjects were part of a an intercollegiate team, and the male participants were part of a club team. Both groups of participants were approached by the researcher, who explained the purpose and process of the study and requested 10 athletes from each team for voluntary participation with no reimbursement other than their own personal results of the study and any possible jump training to correct insufficient biomechanics. Participants signed up for 20 minute sessions with the researcher and were instructed to wear shorts and athletic shoes. Subjects signed an informed consent form prior to participation. The institution the research was conducted at did not have and official IRB board, but was approved by the research ethics committee. Participants were excluded if they were currently suffering knee pain at the time of testing. No participants met those criteria. Average height of the women was 69.05 inches, and the males 73.025 inches. The age range for the women was 18-21, and the range for the men was 18-25.

5.2 Testing Procedures

All testing was performed in an athletic training facility. Participants were given an intake form asking about current knee pain, previous knee surgeries, and if they wished to be notified about the results of the study.

The first test performed was navicular drop to determine foot pronation. The procedures followed those in Starkey, Brown, and Ryan[42]. Participants removed shoes and socks from both feet and sat with the feet touching the floor in a non-weight bearing position. A mark was placed on the foot using a marker over the navicular tuberosity. Then a paper was placed next to the foot and a mark was made corresponding to the level of the navicular tuberosity. The participant was asked to then stand up with their weight evenly distributed between both feet. A new mark was made corresponding with the new level of the navicular tuberosity. The displacement was measured in millimeters. A positive test was identified as measurements that exceeded 10mm[42].



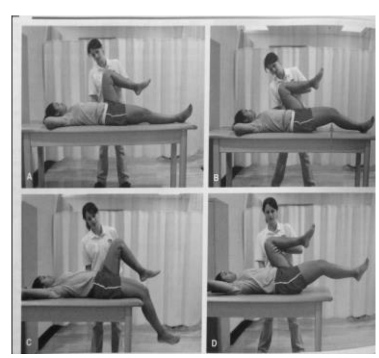
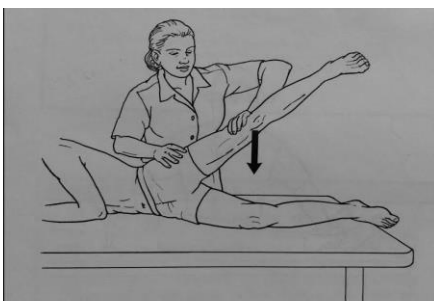


Figure 1. on left. Procedure for the navicular drop test[42]; Figure 2. Group of four on the right. Thomas Test; top two measures at the hip testing for iliopsoas tightness; bottom two images measures at knee testing for rectus femoris[42]

The Thomas test and modified Thomas test for hip flexor tightness was performed with the patient lying supine with the entire body on the table. This procedure was modified from Starkey, Brown, and Ryan[42]. The Thomas test identifies iliopsoas muscle tightness. The patient passively moved the hip and knee into flexion and held the leg close to their chest. Hip flexion was measured by the researcher using a standard goniometer. The Modified Thomas test identifies rectus femoris muscle tightness. The patient then moved to the edge of the table and was asked to hold their knee and roll back onto the table. A half foam roll was placed under the distal femur of the tested leg. This was done to ensure that the upper leg would be at a 90 degree angle to prevent the influence of hip extension or leg muscle or adiposity in knee flexion angles. The knee flexion angle was measured by the researcher. Both tests were assessed bilaterally. Because there are no set normative data for this test, a test was considered positive if there was more than a five degree difference bilaterally, both at the hip and the knee for the purposes of this study.

Gluteus medius strength was determined using established manual muscle testing protocols[13]. Participants were placed in a side lying position with the testing leg on top. The bottom leg was flexed for stability and the top leg was moved into slight hip extension to isolate the gluteus medius. Participants were asked to lift their leg into abduction and cued to make sure they were still in slight hip extension. Participants were then asked to hold their leg in that position why the researcher applied pressure into adduction for six seconds. Scores were graded on a traditional 0-5 scale with 4- and 4+ grading included. A positive test was considered anything less than a five for the purposes of this study, since the participants are high level athletes and high levels of strength are expected.



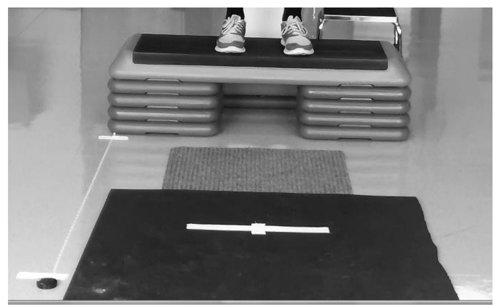


Figure 3. On left. Gluteus Medius strength testing[42]; Figure 4. On right. LESS testing setup

For the LESS, two standard handheld video cameras were set up directly in front of the participant and on the left sagittal view. The camera lenses were 48 inches from the floor and 130 inches away from the landing area. Normally, the cameras should be 138 inches away, but due to space constraints the distance was decreased. A box was setup that was 30cm tall for participants to jump off of. A small carpet runner was placed under a rubber mat to prevent sliding upon landing. A twelve inch strip of tape was placed on the mat for participants to aim for when landing. A tape measure was taped down next to the mat so that the mat could be slid to 50% of the participant's height. Prior to the first jump, the participant's height was measured in inches. The mat was then moved so that the tape was equal with 50% of the height in inches. Participants were then instructed to stand on the box and to jump forward so that their feet bisected the line, then immediately jump maximally, straight up and down so that they would land on the line again. Participants were given two practice jumps, followed by three recorded trial jumps. The dominant leg was assessed by asking participants which leg they would kick a soccer ball with. The dominant leg was scored in the frontal plane view. The LESS score was determined using Dartfish and the LESS scoring parameters to determine an overall score.

For each test (navicular drop, Thomas test, gluteus medius strength), a Pearson correlation was run between the specific test and the final LESS score. This type of testing was chosen to see if the variables were related. The Pearson correlation was coded binomially which worked well because the results were determined as positive (1) or negative (0). A strong correlation was considered if the results were above 0.7. A moderate correlation was 0.5, and a weak correlation 0.3. These cut scores were arbitrarily determined by statistical inference.

6. Results

For each test, the Pearson correlation was run to determine the strength of the relationship between the positive test and a higher overall less score. For women, the correlation between left foot navicular drop and LESS score was -0.24. Right foot navicular drop was -0.53. There was no result for hip flexor tightness at the knee due to the lack of positive scores. For hip flexor tightness around the knee, the score was 0.22. Left gluteus medius strength was -0.09, compared to 0.20 on the right side. For total categories compared to overall LESS, there was a -0.27 correlation.

Table 2. correlation of LESS scores to navicular drop, hip flexor tightness, gluteus medius strength and overall total positive categories

	Test in Correlation to LESS Score						
	Navicular Drop		**Hip Flexor**		**Gluteus Medius Strength**		**Categories Total**
	L	**R**	**HIP**	**KNEE**	**L**	**R**	
Females	-0.24	-0.53	No scores	0.22	-0.09	0.20	-0.27
Std Dev (F)	0.49	0.49	0	0.49	0.49	0.49	1.83
Males	0.24	-0.13	No scores	0.16	0.32	0.48	0.56
Std Dev (F)	0.49	0.29	0	0.49	0.49	0.49	2.57
Both	-0.004	-0.06	No scores	0.13	0.14	0.33	0.29
Std Dev (B)	0.50	0.48	0	0.50	0.49	0.49	2.41

For males, navicular drop on the left side has a 0.24 and the right a -0.13 correlation. There was no score for hip flexor tightness at the hip due to no positive scores by any athlete. However, hip flexor tightness around the hip was 0.16. Gluteus medius strength on the left side was a slight correlation of 0.32 and 0.48 on the right side. Overall categories showed a moderate correlation of 0.56. There was no determination of a causal link between any variables using the Pearson correlation.

For the two groups combined, left foot navicular drop was -0.004 and the right foot was -0.06. Hip flexor tightness at the hip was not calculated due to a lack of positive scores. Hip flexor tightness around the knee the score was 0.13. Gluteus medius strength on the left side was 0.14 and the right was a slight correlation of 0.33. Total categories were 0.29.

A one tailed t-test was run to determine if males and females had a significant difference in overall LESS scores. This was to determine if females had worse landing mechanics overall. Between the average total LESS score of women (8.8) and the average LESS score of the men (7), a t-test was run and yielded a p-value of $p = 0.05$.

7. Discussion

From the results, it is shown in women gluteus medius strength, predominately the right side, and hip flexor tightness at the knee are the factors that best predict a higher LESS score. In men, left foot navicular drop and gluteus medius strength predict a higher score. However, the combination of having a higher number of positive scores in all the categories is the best predictor of a higher LESS score.

The best predictors for a higher LESS score differ between the genders. In women, gluteus medius strength and hip flexor tightness at the knee are the weakly correlated to increased LESS score. In men, a combination of positive scores in more categories leads to the moderate correlation to an increased LESS score. Each individual category has stronger correlations to a higher LESS score in men than in women. This is interesting because more women scored higher in the total categories positive but it seemed to have a stronger correlation with the men's scores. The difference between men's and women's overall LESS scores was not significant at the 5% level, but was at the 6%. However, the 5% significance level is standard. These results were significant at a six percent significance level. This is consistent with past studies because typically women score significantly worse with landing mechanics than males do.

If any of the women were positive for navicular drop, it was in their right foot only or bilaterally positive. There was no case where only the left foot was positive. This could be attributed to a chance, due to the small sample size. There was a mix of left and right leg dominate athletes, so leg dominance should not be the cause of the lack of positive left foot only navicular drop tests. This phenomena is something that may be investigated in the future.

Beutler et al. performed a study which looked at isometric lower-extremity muscular strength, anthropometrics (Q-angle, navicular drop, bodyweight), and jump-landing technique for 2,753 cadets from the U.S. Air Force, Military and Naval Academies. They found that females lacked hip and knee flexion at initial contact, had more knee valgus with a wider landing stance, and less flexion displacement. Males landed in a toe-out position, heels first, and had asymmetric foot landing[3]. The current study found there were similar results with females that had increased knee valgus at initial contact and males having a more toe-out foot position on landing. Beutler et al. study and the current study seem to only agree on two points out of five. This was interesting because these are typically landing mechanics that differ between genders, yet the current study only supported two factors. The difference could be attributed to the population differences, e.g., Division III volleyball players and military cadets, as well as a significantly larger sample size than the current study.

Errors and limitations that may have evolved from this study include: goniometric techniques for the hip flexor tightness at the hip and the knee, LESS scoring, and gluteus medius strength testing. There was no normative data for hip flexor tightness in any population. Due to this lack of comparative or normative data, bilateral differences in measurements were used. When testing hip flexor tightness around the knee, normally a bolster is not used to put the hip into 180° or as close to as possible. This was done to make sure that joint angles were not affected by the size of the upper leg. For the LESS, three trials with a positive score in 2 of the 3 trials were not used, because that data was not found until late into the process. Therefore, the jump-stop task that appeared to be best or most consistent was used for scoring. Also, the author was the only one performing the LESS scoring for each individual, which maintained intra-relater reliability. However, the author had not performed the LESS evaluation prior to this testing, and therefore may have over- or under-estimated the results. Relative to the gluteus medius strength testing, the author found that most athletes scored very high and the differention from a five and a four score was difficult. It would have been more standardized had a hand-held isometric dynamometer been used.

In relation to the hypothesis that having a positive navicular drop measurement, tight hip flexors, and weaker gluteus medius would lead to a higher LESS score in volleyball players, it appears to be trending in this direction with the males. The more of the categories that each individual falls into, the higher their LESS score tends to be. Females showed a negative correlation, which means that it trends that the more categories they are positive in, the lower their LESS score tends to be. This could be that female volleyball athletes are not at an increased risk for injury due to navicular drop, hip flexor tightness and gluteus medius strength. Gluteus medius strength and hip flexor tightness do appear to play a role in a higher LESS score, but the combination of all of the tests, does not. Overall these are factors that can be addressed with prevention programs, strengthening, stretching, or the use of orthotics to help prevent ACL injuries while landing from a jump.

Overall, this study found that navicular drop, hip flexor tightness, and gluteus medius strength do not trend with increasing LESS scores in females. There appears to be more than just these three factors that predispose women to incorrect landing biomechanics. Different intrinsic and extrinsic factors should be explored to give a more rounded view of what causes faulty biomechanics in females. To find what causes women to have a high LESS score needs more research on. There is some evidence that gluteus medius strength and tightness in the rectus femoris could lead to a higher score, but there is more to be tested and evaluated before making the assumption that these two factors have a significant effect on LESS scores. In males, a total combination of the three tests seems to trend with an increase in LESS scores. This data suggests that navicular drop, hip flexor tightness, and gluteus medius strength should be addressed in male volleyball players to decrease LESS scores and possible injury risk.

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9. References

1. ACL injury: Does it require surgery? (2009, September). Retrieved April 29, 2015, from OrthoInfor: http://orthoinfo.aaos.org/topic.cfm?topic=a00297
2. Belanger, M. J., Moore, D. C., Crisco III, J. J., Fadale, P. D., Hulstyn, M. J., & Ehrlich, M. G. (2004). Knee laxity does not vary with the menstrual cycle, before or after exercise. *The American Journal of Sports Medicine*, 32(5), 1150-1157.
3. Beutler, A., de la Motte, S., Marshall, S., Padua, D., & Boden, B. (2009). Muscle strength and qualitative jump-landing differences in male and female military cadets: The jump-ACL study. *Journal of Sports Medicine and Science*, 8(4), 663-671.
4. Beynnon, B. D., Vacek, P. M., Newell, M. K., Tourville, T. W., Smith, H. C., Shultz, S. J….Johnson, R. J. (2014). The effects of level of competition, sport, and sex on the incidence of first-time noncontact anterior cruciate ligament injury. *The American Journal of Sports Medicine*, 42(8), 1806-1812.
5. Blackburn, J. T., & Padua, D. A. (2008). Influence of trunk flexion on hip and knee joint kinematics during a controlled drop landing. *Clinical Biomechanics*, 23, 313-319.
6. Distefano, L. J., Blackburn, J. T., Marshall, S. W., & Padua, D. A. (2009). Gluteal muscle activation during common therapeutic exercises. *Journal of Orthopaedic and Sports Physical Therapy*, 39(7), 532-540.
7. Dragoo, J. L., Braun, H. J., & Harris, A. H. (2013). The effect of playing surface on the incidence of ACL injuries in national collegiate athletic association american football. *In The Knee*, 20(3), 191-195.
8. Dragoo, J. L., Castillo, T. N., Braun, H. J., Ridley, B. A., Kennedy, A. C., & Golish, S. R. (2011). Prospective correlation between serum relaxin concentration and anterior cruciate ligament tears among elite collegiate female athletes. *The American Journal of Sports Medicine*, 39(10), 2175-2180.
9. Granan, L., Inacio, M. C., Maletis, G. B., Funahashi, T. T., & Engebretsen, L. (2013). Sport-specific injury pattern recorded during anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine*, 41(12), 2814-2818.
10. Guccione, A. A., Felson, D. T., Anderson, J. J., Anthony, J. M., Zhang, Y., Wilson, P. W….Kannel, W. B. (1994). The effects of specific medical conditions on the functional limitations of elders in the framinham study. *American Journal of Public Health*, 84(3), 351-358.
11. Hewett, T. E., Ford, K. R., Hoogenboom, B. J., & Myer, G. D. (2010). Understanding and preventing ACL injuries: Current biomechanical and epidemiologic considerations - update 2010. *North American Journal of Sports Physical Therapy*, 5(4), 234-251.
12. Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G....Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. *The American Journal of Sports Medicine*, 33(4), 492-501.
13. Hislop, H. J., & Montgomery, J. (2007). Daniels & Worthinghams muscle testing: Techniques of manual examination (8th ed.). St. Louis, MO: Saunders Elsevier.
14. Hootman, J. M., Dick, R., & Agel, J. (2007). Epidemiology of collegiate injuries for 15 sports: Summary and recommendations for injury prevention initiatives. *Journal of Athletic Training*, 42(2), 311-319.
15. Ireland, M. L., Willson, J. D., Ballantyne, B. T., & Davis, I. M. (2003). Hip strength in females with and without patellofemoral pain. *Journal of Orthopaedic & Sports Physical Therapy*, 33(11), 671-676.
16. Jones, G. (2012). Rugby injuries. Sports Medicine Update, 2-7.
17. Joseph, A. M., Collins, C. L., Henke, N. M., Yard, E. E., Fields, S. K., & Comstock, R. D. (2013). A multisport epidemiologic comparison of anterior cruciate ligament injuries in high school athletics. *Journal of Athletic Training*, 48(6), 810-817.
18. Kim, J. (2009, January). Anterior Cruciate LIgament Injury. (J. Smith, Editor, & University of California San Diego) Retrieved December 2014, from Department of Orthopaedic Surgery: http://orthosurg.ucsf.edu/patient-care/divisions/sports-medicine/conditions/knee/anterior-cruciate-ligament-injury-acl/
19. Kobayashi, H., Kanamura, T., Koshida, S., Miyashita, K., Okado, T., Shimizu, T., & Yokoe, K. (2010). Mechanisms of the anterior cruciate ligament injury in sports activities: A twenty-year clinical research of 1,700 athletes. *Journal of Sports Science and Medicine*, 9, 669-675.
20. LaBella, C., Nistler, C., Carl, R., & Hang, B. T. (n.d.). Institute for Sports Medicine. Retrieved April 27, 2015, from Ann and Robert H. Lurie Children's Hospital of Chicago: https://www.luriechildrens.org/en-us/care-services/specialties-services/institute-for-sports-medicine/Pages/index.aspx

21. Lawrence, R. C., Felson, D. T., Helmick, C. G., Arnold, L. M., Choi, H., Deyo, R. A….National Arthritis Data Workgroup. (2008). Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part II. *Arthritis & Rheumatology*, 58(1), 26-35.

22. Levy, A. S., Wetzler, M. J., Lewars, M., & Laughlin, W. (1997). Knee injuries in women collegiate rugby players. *The American Journal of Sports Medicine*, 25(3), 360-362.

23. Lin, C. F., Gross, M., Ji, C., Padua, D., Weinhold, P., Garrett, W. E., & Yu, B. (2008). A stochastic biomechanical model for risk and risk factors of non-contact anterior cruciate ligament injuries. *Journal of Biomechanics.*

24. Mather III, R. C., Koenig, L., Kocher, M. S., Dall, T. M., Gallo, P., Scott, D. J….Spindler, K. P. (2013). Societal and economic impact of anterior cruciate ligament tears. *Journal of Bone and Joint Surgery*, 95-A(19), 1751-1759.

25. McCurdy, K., Walker, J., Armstrong, R., & Langford, G. (2014). Relationship between selected measures of strength and hip and knee excursion during unilateral and bilateral landings in women. *Journal of Strength and Conditioning*, 28(9), 2429-2436.

26. Meunier, A., Odensten, M., & Good, L. (2007). Long-term results after primary repair of non-surgical treatment of anterior cruciate ligament rupture: A randomized study with a 15-year follow-up. *Scandinavian Journal of Medicine & Science in Sports*, 17, 230-237.

27. Noyes, F. R., & Barber-Westin, S. D. (2014). Neuromuscular retraining intervention programs: Do they reduce noncontact anterior cruciate ligament injury rates in adolescent female athletes? *Arthroscopy: The Journal of Arthroscopic and Related Surgery*, 30(2), 245-255.

28. Noyes, F. R., Barber-Westin, S., Campbell, T., & Smith, S. (n.d.). (Cincinnati Sportsmedicine and Orthopaedic Center) Retrieved from Sportsmetrics USA: http://sportsmetrics.org/

29. Olsen, O. E., Myklebust, G., Engebretsen, L., & Bahr, R. (2004). Injury mechanisms for anterior cruciate ligament injuries in team handball: A systematic video analysis. *The American Journal of Sports Medicine*, 32(4), 1002-1012.

30. Orchard, J. W., & Powell, J. W. (2003). Risk of knee and ankle sprains under various weather conditions in american football. *Medicine & Science in Sports & Exercise*, 1118-1123.

31. Padua, D. A., Marshall, S. W., Boling, M. C., Thigpen, C. A., Garrett Jr, W. E., & Beutler, A. I. (2009). The landing error scoing system (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study. *The American Journal of Sports Medicine*, 1-7.

32. Paterno, M. V., Schmitt, L. C., Ford, K. R., Rauh, M. J., Myer, G. D., & Hewett, T. E. (2011). Effects of sex on compensatory landing strategies upon return to sport after anterior cruciate ligament reconstruction. *Journal of Orthopaedic & Sports Physical Therapy*, 41(8), 553-559.

33. Peck, K. Y., Johnston, D. A., Owens, B. D., & Cameron, K. L. (2013). The incidence of injury among male and female intercollegiate rugby players. *Sports Health*, 5(4), 327-333.

34. Renstrom, P., Ljungqvist, A., Arendt, E., Beynnon, B., Fukubayashi, T., Garrett, W., et al. (2008). Non-contact ACL injuries in female athletes: An International Olympic Committee current concepts statement. *British Journal of Sports Medicine*, 46(2), 394-412.

35. Scranton, P. E., Whitesel, J. P., Powell, J. W., Dormer, S. G., Heidt, R. S., Losse, G., et al. (1997). A review of selected noncontact anterior cruciate ligament injuries in the national football league. *Foot & Ankle International*, 18(12), 772-776.

36. Shimokochi, Y., & Shultz, S. J. (2008). Mechanisms of noncontact anterior cruciate ligament injury. *Journal of Athletic Training*, 43(4), 396-408.

37. Shultz, S. J., Kirk, S. E., Johnson, M. L., Sander, T. C., & Perrin, D. H. (2004). Relationship between sex hormones and anterior knee laxity across the menstrual cycle. *Medicine & Science in Sports & Exercise*, 1165-1174.

38. Silvers, H., Schlegel, S., & Dao, D. (n.d.). Retrieved April 27, 2015, from Santa Monica Sports Medicine Foundation: http://smsmf.org/

39. Slauterbeck, J. R., Fuzie, S. F., Smith, M. P., Clark, R. J., Xu, K. T., Starch, D. W., & Hardy, D. M. (2002). The menstrual cycle, sex hormones, and anterior cruciate ligament injury. *Journal of Athletic Training*, 37(3), 275-280.

40. Smith, H. C., Vacek, P., Johnson, R. J., Slauterbeck, J. R., Hashemi, J., Shultz, S., & Beynnon, B. D. (2012). Risk Factors for Anterior Cruciate Ligament Injury: A Review of the Literature - Part 1: Neuromuscular and Anatomic Risk. *Sports Health: A Multidisciplinary Approach*, 4(1), 69-78.

41. Starkey, C., & Brown, S. D. (2015). Examination of orthopedic & athletic injuries (4th ed.). Philadelphia, PA: E.A. Davis Company.

42. Starkey, C., Brown, S. D., & Ryan, J. (2010). Examination of othopedic and athletic injuries (3rd ed.). Philadelphia, PA: E.A. Davis Company.
43. Voskanian, N. (2013). Women's issues (Ma Goolsby, Section editor) ACL Injury prevention in female athletes: review of the literature and practical considerations in implementing an ACL prevention program. *Current Reviews in Musculoskeletal Medicine*, 6, 158-163