Anatomic Factors that May Predispose Female Athletes to Anterior Cruciate Ligament Injury

Edward C. Cheung, MD; Daniel V. Boguszewski, PhD; Nirav B. Joshi, MD; Dean Wang, MD; and David R. McAllister, MD

Abstract

Female athletes are 2 to 10 times more likely to injure their anterior cruciate ligaments (ACL) than male athletes. There has been greater recognition of this gender discrepancy because female participation in competitive athletics has increased. Previous investigators have divided risk factors into hormonal, neuromuscular response, and anatomic subgroups. Gender variation within these groups may help explain the higher incidence of ACL injury in women. The purpose of this article is to review research examining female-specific anatomy that may predispose women to ACL injury. Specifically, we discuss how women may have increased tibial and meniscal slopes, narrower femoral notches, and smaller ACL, which may place the ACL at risk from injury. These anatomic factors, combined with other female-specific risk factors, may help physicians and researchers better understand why women appear to be more prone to ACL injury.

Introduction

The anterior cruciate ligament (ACL) is a primary stabilizer of the knee, accounting for 85% of the total restraint to anterior tibial translation (6). Injury to the ACL occurs frequently, comprising 40% to 50% of all ligamentous knee injuries (17). Over 70% of ACL ruptures occur in noncontact situations during sudden change of direction or landing during athletic activities and sports such as football, soccer, basketball, and skiing (5). The injured ACL has little capacity for healing. Conservative, nonoperative treatment of an ACL injury can result in a significantly higher lifetime financial burden due to decreased productivity and lost wages (31). The ACL-deficient knee also can lead to the inability to participate in athletics and is associated with an increased incidence of early knee osteoarthritis, causing an increase in patient morbidity, permanent disability, and a decrease in quality of life (12,31,32,48). For these reasons, surgical reconstruction of the ACL has become one of the more common procedures in the orthopedic community, with more than 200,000 reconstructions performed annually in the United States (31). Unfortunately, even after ACL reconstruction is performed, there is a risk of developing early-onset osteoarthritis (27,47). Given the long-term prognosis after ACL injury and considering that health care expenditures have steadily increased over the past 20 years (36), there is growing interest in prevention and identifying individual risk factors to help prevent ACL injuries.

Female participation in competitive athletics has increased significantly in recent years (1,21). Compared with their male counterparts, women are at a 2 to 10 times greater risk from ACL injury (2,14). As a result, ACL injury is now a more frequent occurrence in women than in men (5). This gender discrepancy has shifted the focus of ACL injury prevention research to identify female-specific characteristics that may make them more prone to ACL injury. In a summary of a 2005 meeting on ACL injury prevention, Griffin et al. (13) divided ACL risk factors into four categories: environmental (playing surface), hormonal (influence of estrogen) (3,7), neuromuscular (increased muscle response times in women) (18,21), and anatomic variation (13). Given the gender disparity in ACL injury, most of these divisions are related to gender differences. A discussion of each category is beyond the scope of this article. Instead, we will review how gender-specific anatomic differences may play a role in female ACL injury.

The ACL spans the tibiofemoral articulation, and its inherent strength and the biomechanical milieu is influenced by its surrounding anatomy. Researchers have demonstrated universal anatomic characteristics inherent to the knee that place the ACL at greater risk from injury. The purpose of this article is to highlight the differences of these key anatomic features and discuss possible explanations for the increased incidence of ACL injury among women. Specifically, the focus will be on research related to risk factors

Biomechanics Research Section, Department of Orthopaedic Surgery, University of California at Los Angeles, Los Angeles, CA

Address for correspondence: Edward C. Cheung, MD, Rm 22-46, UCLA Rehab Center, 1000 Veteran Ave., Los Angeles, CA 90095; E-mail: echeung@mednet.ucla.edu.

1537-890X/1405/368–372
Current Sports Medicine Reports

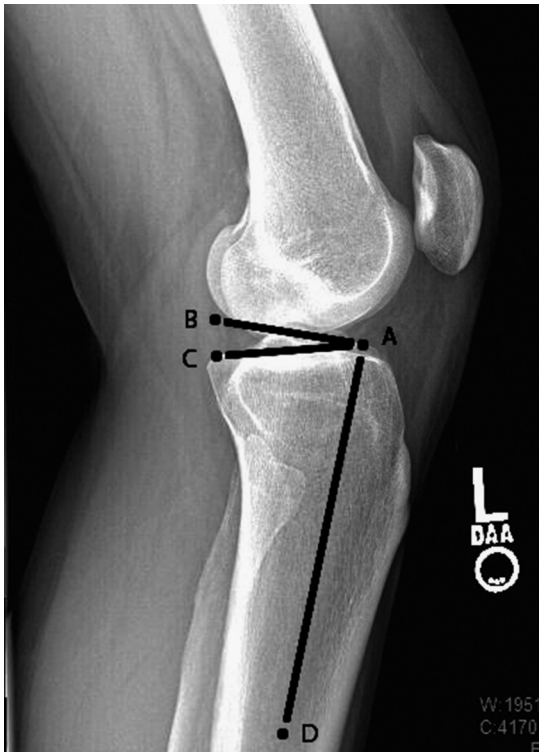

Figure 1: Tibial slope is the angle formed between lines A–B and A–C. A–D is a line parallel to the tibial shaft, and A–B is a perpendicular line to A–D. Points A and C are on the anterior and posterior aspects of the tibial plateau.

associated with tibial and meniscal anatomy, femoral notch morphology, and ACL size.

Tibial Anatomy

Tibial Plateau Slope

Load transmission across the knee is influenced by its bony and articular architecture. In the normal knee, there is a posterior to anterior inclination of the tibial plateau in the sagittal plane termed the posterior tibial slope (PTS). It has been defined as the angle formed between a line perpendicular to the longitudinal axis of the tibia and a line along the sagittal inclination of the tibial plateau (Fig. 1).

Women have been identified as being more prone to having increased PTS compared with men (15,16,45). However, it appears that the medial and lateral tibial slopes do not play an equal role, and the magnitude of the lateral tibial slope may be an independent risk factor for injury. If the lateral PTS is greater than the medial PTS, the tibia will internally rotate during weight bearing (Fig. 2) (39). During a simulated pivot landing, Lipps et al. (26) demonstrated that women not only had greater lateral PTS than men, but also had greater internal rotation and greater ACL strain during the simulated landing (26). Their group hypothesized that the increased tibial motion and ACL strain were results of an increased lateral PTS.

The overall contribution of PTS on anterior tibial translation has been examined in both animal (40,41) and human (10,30) knees. Slocum and Devine (40,41) first described the influence of the PTS on anterior tibial translation in the knee in 1983 and 1984 when they performed slope-reducing osteotomies in dogs, which decreased anterior translation of the tibia. In a human cohort of 281 patients, Dejour and Bonnin (10) measured an average PTS of 10° ± 3° in patients deemed to have normal knees and demonstrated that for every 10° increase in PTS, the tibia translated 3.5 mm anteriorly on a radiographic Lachman's exam.

Variations in the PTS are associated with changes in relative tibiofemoral motions. A larger lateral PTS tends to increase anterior tibial subluxation and internal tibial rotation, and are both known to increase force generation within the ACL (29). In fact, force generation within the ACL is greatest when the tibia is anteriorly translated, in valgus, and internally rotated, suggesting that PTS alone can have a significant effect on ACL force. Current models suggest a linear relationship between the PTS and the anterior tibial translation during weight-bearing conditions: given a greater PTS with application of an axial joint load, there is greater tibial translation, which places greater anterior shear forces on the knee (30). As shown by Meyer et al. (33), axial loading alone can cause ACL rupture (33). Furthermore, an increased PTS would accentuate normal anterior tibial translations and internal rotations commonly seen during sudden loading conditions like landing from a jump or a cutting maneuver (4). Therefore, one possible explanation for the gender differences in ACL injury may be the overall greater PTS seen in women, with the lateral tibial slope playing a larger role than the medial tibial slope.

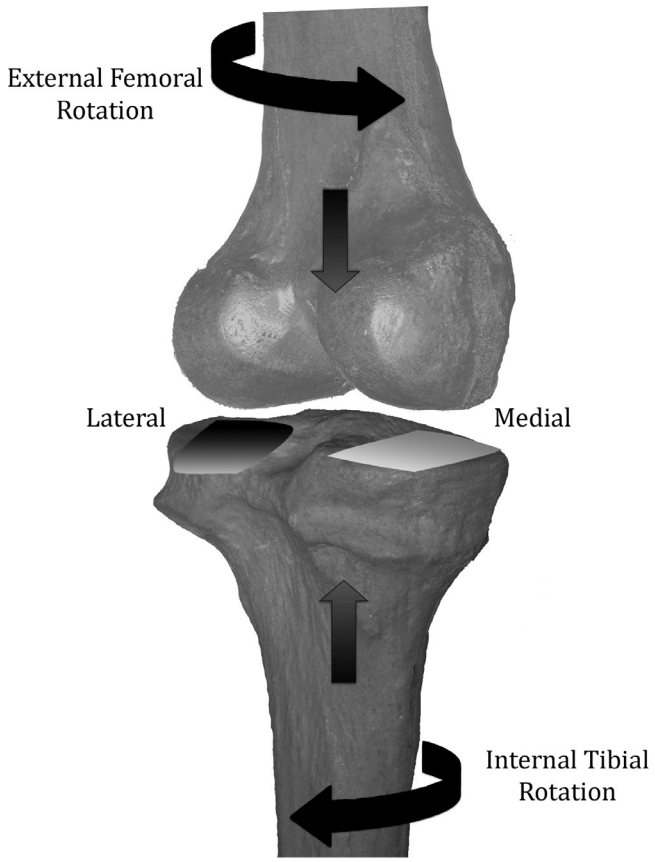

Figure 2: Increased lateral tibial slope compared with the medial slope causes tibial internal rotation during axial loading.

Meniscal Slope

The menisci are fibrocartilaginous, semilunar-shaped structures attached to the tibial plateau and act as a soft tissue extension of the bony tibial anatomy. They play a critical role in shock absorption and reduce frictional forces experienced by the knee during loading. Combined with the knowledge that the bony tibial slope is a risk factor for ACL injury in women and that the menisci are vital secondary stabilizers to the knee, researchers have examined the role of the anterior-posterior meniscal slope on ACL injury.

Similar to the tibial plateau, a meniscal slope is a quantifiable measure. It is defined as the angle between the tangent line of the superiormost border of the ipsilateral anterior and posterior meniscus and the longitudinal axis of the tibia (20,23). The meniscus and the tibia both have posterior slopes but do not consistently have equivalent values. The variation between the tibial slope and the meniscal slope has led some researchers to hypothesize that the meniscal slope may be more important than the PTS as a risk factor for ACL injury (23). In patients who have undergone meniscectomy, reports have documented increased anterior-posterior tibial motion (19,44). Levy et al. (25) demonstrated increases in anterior tibial translation 4 mm upward after medial meniscectomy in cadaveric ACL-deficient knees. Hudek et al. (20) found greater lateral meniscal slopes among men and women with noncontact ACL injuries compared with uninjured patients. More importantly, they also demonstrated a greater inherent meniscal slope in uninjured women compared with their male counterparts (20). Levy et al. (25) showed that the posterior meniscal horn acts like a wedge between the articulating bony surfaces to restrain excess anterior tibial motion, whereas the lateral meniscus does not. Musahl et al. (35) later demonstrated that upon performing a pivot shift maneuver in a combined lateral meniscus-deficient and ACL-deficient knee, an additional 6 mm of anterior motion was noted compared with ACL-deficient knees with an intact meniscus, suggesting that the lateral meniscus confers some protection against anterior motion during combined valgus and rotatory movements, which is common in athletics.

The greater native meniscal slope seen in women may increase the overall risk of ACL injury. In addition, decreased posterior meniscal height due to injury or chronic degeneration can cause further inclination of the meniscal slope and ultimately present as an important risk factor for ACL injury (20,43). Together, the magnitude of the tibial and meniscal slopes has been shown to influence the biomechanics of the knee during load transmission. Gender differences in the PTS and the meniscal slope may contribute to the increased incidence of female ACL injury.

Femoral Anatomy

Femoral Notch

Consideration of femoral notch morphology as a potential risk factor for ACL injury comes from the positioning of the cruciate ligaments, which are contained within the femoral notch in the knee. Women are generally smaller than men, leading to the assumption that the femoral notch and the ACL are both concomitantly smaller in women. The most commonly described mechanism of injury for ACL tears is a noncontact twisting motion of the knee, where the femur rotates on the tibia (34). Because the ACL lies within the femoral notch, one proposed explanation for rupture of the ACL during this movement is impingement of the ACL on the lateral border of the femoral notch. Intraoperatively, many physicians perform notchplasties to increase the width of the femoral notch and decrease the risk of impingement and reinjury. This observation has led researchers to examine whether the morphology of the femoral notch or the size of the ACL within the notch is correlated with ACL injury. Researchers have suggested that a narrow femoral notch is an independent risk factor for ACL injury (22,24,39,46,49–51). In a 2013 meta-analysis examining studies from 1994 to 2011, Zeng et al. (51) concluded that a narrow femoral notch was strongly associated with an increased risk of ACL injury.

Many studies support the assumption that women have smaller femoral notches than men (11,38,46,50). In an attempt to control for variations in patient height and weight, in 1988, Souryal et al. (42) described the notch width index (NWI), which is the ratio of the notch at the outlet to the width of the femoral condyles at the popliteal groove (Fig. 3). Using this method, LaPrade and Burnett (24) in 1994 prospectively followed 213 collegiate level athletes for 2 years after obtaining notch view x-rays and found that a NWI <0.2 placed athletes at a higher risk from ACL injury. Although there was a trend toward women having a smaller NWI than men, the authors did not find a statistical difference. In a

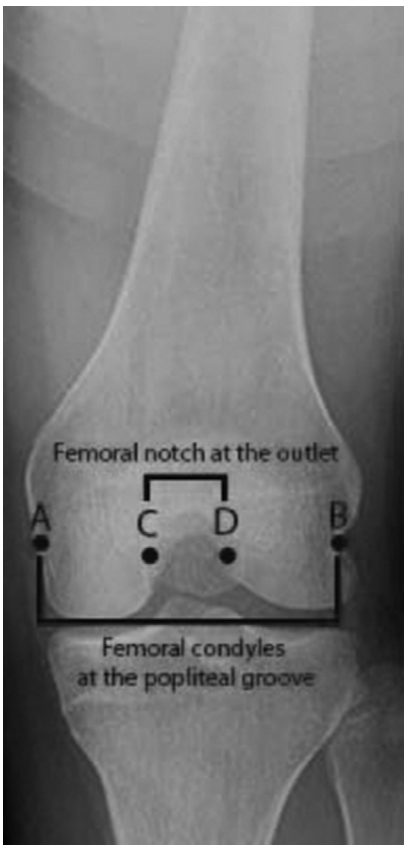

Figure 3: Femoral NWI is the ratio of the width of the femoral notch at the outlet (CD) to the width of the femoral condyles at the level of the popliteal groove (AB).

1998 study by Shelbourne et al., the authors examined 714 patients undergoing ACL reconstruction and found that patients with an absolute notch width of <15 mm had a 5.9% increased chance of contralateral ACL injury compared with 1.2% in patients with an absolute notch width of >16 mm. They also found that women of the same height/weight as men have narrower notches, and that femoral bicondylar width increased with patient weight, but notch size did not, causing the NWI to be inappropriately lowered.

However, the theory that femoral notches in women are smaller than those of the male counterparts is controversial. There are many studies that refute the idea that femoral notch size is an independent risk factor for ACL injury, as well as the notion that women have overall smaller femoral notches when normalized for height and weight. Schickendantz and Weiker (37) showed no significant differences in NWI between 31 knees in 24 patients with bilateral ACL injuries, 30 patients with unilateral ACL injuries, and 30 patients without ACL injury. In a 2005 study by Lombardo et al. (28) examining 305 NBA players between 1992 and 1999, there were no significant differences in the rate of ACL injury in players with NWI of 0.2 or in players with absolute notch widths <15 mm as observed by Souryal and Shelbourne, respectively. In a descriptive anatomic study of 50 male and 50 female high school basketball players, Anderson et al. (1) also found no differences between male and female NWI values.

In 2005, during a meeting examining ACL injury, the researchers suggested that the difficulty when comparing studies examining notch morphology against one another is that many are underpowered (13), and each use varying methodologies ranging from arthroscopy, magnetic resonance imaging (MRI), and x-ray measurements to direct cadaveric measurements with calipers. There also is disagreement within the literature regarding what bony landmarks to use when measuring the femoral notch itself. Therefore, a consensus statement that women have smaller notches than men and that it is an independent risk factor for ACL injury cannot be reached at this time; however, there may be a trend toward women having smaller femoral notches. Further research in this area using a standardized method for measuring the femoral notch with a greater number of participants is needed to support or refute this assumption.

ACL Size and Morphology

Various studies have shown that women have smaller ACL compared with men, but similar to the research on femoral notches, there is no universal consensus as to the measurement methodology for ACL size. Some studies examine the midsubstance cross-sectional area, some measure the ACL footprint, and some estimate the size of the ligament based on the best-fit rectangles as seen on MRI. However, even with variation in methodologies, it is generally accepted that women have smaller ACL than men, and that smaller ACL, when subjected to the same level of force, is more prone to rupture than larger ligaments.

Lipps et al. (26) in 2012 demonstrated that the cross-sectional area of the ACL was significantly correlated to ACL strain. In a cadaveric study of 20 specimens, Chandrashekar et al. (8) showed that female ACL was smaller in length, cross-sectional area, mass, and density compared with men. These gender differences in size also have led to the notion that there are gender differences within the structural properties of the ACL as well. Female ACL exhibits lower strain, stress, and modulus of elasticity at failure compared with men (16). Lipps et al. (26) in 2012 measured peak ACL forces in 20 cadaveric knees during a simulated pivot landing and showed that the anteromedial bundle of the ACL in female specimens exhibited 95% increased strain compared with male counterparts.

Another theory is that ligament size and notch size are related. The femoral notch houses the ACL; consequently, the size of ACL relative to the dimensions of the femoral notch may have important implications. If a smaller notch houses a smaller ACL, then from basic biomechanical principles, a smaller ACL would be less resistant to tensile forces. Conversely, a disproportionately large ligament within a small notch could lead to impingement during internal rotation and valgus loading, which some theorize that this increases the risk of ACL rupture.

Whitney et al. (49) performed a case control study of 176 athletes with first-time grade 3 ACL injuries using MRI to measure ACL and femoral notch size. They found that decreased notch width, ACL size, and cross-sectional area of the ACL were all independent risk factors for ACL injury in men, and that weight, height, and body mass index, when included in regression analyses, also were risk factors for women. Chandrashekar et al. (8) found that the size of the ACL changed proportionally for men, but not for women. Conversely, using MRI, Charlton et al. (9) showed that for both men and women, as the notch changed in size, the ligament correspondingly changed in size. Further research in the relationship between ACL size and notch size is needed to determine whether there are gender differences regarding proportional size differences.

Conclusions

Women are more likely to injure their ACL compared with men. Women have been shown to have increased posterior tibial and meniscal slopes, decreased femoral notch sizes, and smaller native ligaments compared with men. These anatomic differences may help explain the gender disparity in ACL injury rates. Because of differences in methodology and relatively small sample sizes, further research is needed to determine whether these anatomic differences can be used to predict if certain women are more prone to ACL injury.

Acknowledgment

Salary support was provided in part by HH Lee Surgical Scholar Program for Edward C. Cheung.

The authors declare no conflicts of interest.

References

1. Anderson AF, Dome DC, Gautam S, *et al.* Correlation of anthropometric measurements, strength, anterior cruciate ligament size, and intercondylar notch characteristics to sex differences in anterior cruciate ligament tear rates. *Am. J. Sports Med.* 2001; 29:58–66.
2. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *Am. J. Sports Med.* 1995; 23:694–701.

3. Beynnon BD, Bernstein IM, Belisle A, *et al*. The effect of estradiol and progesterone on knee and ankle joint laxity. *Am. J. Sports Med.* 2005; 33: 1298–304.
4. Beynnon BD, Hall JS, Sturnick DR, *et al*. Increased slope of the lateral tibial plateau subchondral bone is associated with greater risk of noncontact ACL injury in females but not in males: a prospective cohort study with a nested, matched case-control analysis. *Am. J. Sports Med.* 2014; 42:1039–48.
5. Boden BP, Dean GS, Feagin JA Jr, Garrett WE Jr. Mechanisms of anterior cruciate ligament injury. *Orthopedics*. 2000; 23:573–8.
6. Butler DL, Noyes FR, Grood ES. Ligamentous restraints to anterior–posterior drawer in the human knee. A biomechanical study. *J. Bone Joint Surg. Am.* 1980; 62:259–70.
7. Cammarata ML, Dhaher YY. The differential effects of gender, anthropometry, and prior hormonal state on frontal plane knee joint stiffness. *Clin. Biomech*. 2008; 23:937–45.
8. Chandrashekar N, Slauterbeck J, Hashemi J. Sex-based differences in the anthropometric characteristics of the anterior cruciate ligament and its relation to intercondylar notch geometry: a cadaveric study. *Am. J. Sports Med*. 2005; 33:1492–8.
9. Charlton WP, St John TA, Ciccotti MG, *et al*. Differences in femoral notch anatomy between men and women: a magnetic resonance imaging study. *Am. J. Sports Med*. 2002; 30:329–33.
10. Dejour H, Bonnin M. Tibial translation after anterior cruciate ligament rupture. Two radiological tests compared. *J. Bone Joint Surg. Br.* 1994; 76:745–9.
11. Everhart JS, Flanigan DC, Chaudhari AM. Anteromedial ridging of the femoral intercondylar notch: an anatomic study of 170 archival skeletal specimens. *Knee Surg. Sports Traumatol. Arthrosc.* 2014; 22:80–7.
12. Friel NA, Chu CR. The role of ACL injury in the development of posttraumatic knee osteoarthritis. *Clin. Sports Med.* 2013; 32:1–12.
13. Griffin LY, Albohm MJ, Arendt EA, *et al*. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. *Am. J. Sports Med*. 2006; 34:1512–32.
14. Gwinn DE, Wilckens JH, McDevitt ER, *et al*. The relative incidence of anterior cruciate ligament injury in men and women at the United States Naval Academy. *Am. J. Sports Med*. 2000; 28:98–102.
15. Hashemi J, Chandrashekar N, Gill B, *et al*. The geometry of the tibial plateau and its influence on the biomechanics of the tibiofemoral joint. *J. Bone Joint Surg. Am*. 2008; 90:2724–34.
16. Hashemi J, Mansouri H, Chandrashekar N, *et al*. Age, sex, body anthropometry, and ACL size predict the structural properties of the human anterior cruciate ligament. *J. Orthop. Res*. 2011; 29:993–1001.
17. Hirschman HP DD, Miyasaka K. The fate of unoperated knee ligament injuries. In: Daniel D, editor. *Knee Ligaments Structure Function. Injury and Repair.* New York: Raven Press; 1990. p. 481–503.
18. Hsu WH, Fisk JA, Yamamoto Y, *et al*. Differences in torsional joint stiffness of the knee between genders: a human cadaveric study. *Am. J. Sports Med.* 2006; 34:765–70.
19. Huckell J. Is meniscectomy a benign procedure? A long-term follow-up study. *Can. J. Surg.* 1965; 8:254–260.
20. Hudek R, Fuchs B, Regenfelder F, Koch PP. Is noncontact ACL injury associated with the posterior tibial and meniscal slope? *Clin. Orthop. Relat. Res.* 2011; 469:2377–84.
21. Huston LJ, Wojtys EM. Neuromuscular performance characteristics in elite female athletes. *Am. J. Sports Med.* 1996; 24:427–36.
22. Ireland ML, Ballantyne BT, Little K, McClay IS. A radiographic analysis of the relationship between the size and shape of the intercondylar notch and anterior cruciate ligament injury. *Knee Surg. Sports Traumatol. Arthrosc.* 2001; 9:200–5.
23. Jenny JY, Rapp E, Kehr P. Proximal tibial meniscal slope: a comparison with the bone slope. *Rev. Chir. Orthop. Reparatrice Appar. Mot.* 1997; 83:435–8.
24. LaPrade RF, Burnett QM 2nd. Femoral intercondylar notch stenosis and correlation to anterior cruciate ligament injuries. A prospective study. *Am. J. Sports Med.* 1994; 22:198–202; discussion 3.
25. Levy IM, Torzilli PA, Warren RF. The effect of medial meniscectomy on anterior–posterior motion of the knee. *J. Bone Joint Surg. Am.* 1982; 64: 883–8.
26. Lipps DB, Oh YK, Ashton-Miller JA, Wojtys EM. Morphologic characteristics help explain the gender difference in peak anterior cruciate ligament strain during a simulated pivot landing. *Am. J. Sports Med.* 2012; 40:32–40.
27. Lohmander LS, Ostenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. *Arthritis Rheum.* 2004; 50:3145–52.
28. Lombardo S, Sethi PM, Starkey C. Intercondylar notch stenosis is not a risk factor for anterior cruciate ligament tears in professional male basketball players: an 11-year prospective study. *Am. J. Sports Med.* 2005; 33:29–34.
29. Markolf KL, Gorek JF, Kabo JM, Shapiro MS. Direct measurement of resultant forces in the anterior cruciate ligament. An in vitro study performed with a new experimental technique. *J. Bone Joint Surg. Am.* 1990; 72: 557–67.
30. Markolf KL, Jackson SR, Foster B, McAllister DR. ACL forces and knee kinematics produced by axial tibial compression during a passive flexion-extension cycle. *J. Orthop. Res.* 2014; 32:89–95.
31. Mather RC 3rd, Koenig L, Kocher MS, *et al*. Societal and economic impact of anterior cruciate ligament tears. *J. Bone Joint Surg. Am.* 2013; 95:1751–9.
32. McLean SG, Mallett KF, Arruda EM. Deconstructing the anterior cruciate ligament: what we know and do not know about function, material properties, and injury mechanics. *J. Biomech. Eng.* 2015; 137:020906.
33. Meyer EG, Haut RC. Excessive compression of the human tibio-femoral joint causes ACL rupture. *J. Biomech.* 2005; 38:2311–6.
34. Meyer EG, Haut RC. Anterior cruciate ligament injury induced by internal tibial torsion or tibiofemoral compression. *J. Biomech.* 2008; 41:3377–83.
35. Musahl V, Citak M, O'Loughlin PF, *et al*. The effect of medial versus lateral meniscectomy on the stability of the anterior cruciate ligament-deficient knee. *Am. J. Sports Med.* 2010; 38:1591–7.
36. Sathiyakumar V, Jahangir AA, Mir HR, *et al*. Patterns of costs and spending among orthopedic surgeons across the United States: a national survey. *Am. J. Orthop.* 2014; 43:E7–13.
37. Schickendantz MS, Weiker GG. The predictive value of radiographs in the evaluation of unilateral and bilateral anterior cruciate ligament injuries. *Am. J. Sports Med.* 1993; 21:110–3.
38. Shelbourne KD, Davis TJ, Klootwyk TE. The relationship between intercondylar notch width of the femur and the incidence of anterior cruciate ligament tears. A prospective study. *Am. J. Sports Med.* 1998; 26:402–8.
39. Simon RA, Everhart JS, Nagaraja HN, Chaudhari AM. A case-control study of anterior cruciate ligament volume, tibial plateau slopes and intercondylar notch dimensions in ACL-injured knees. *J. Biomech.* 2010; 43:1702–7.
40. Slocum B, Devine T. Cranial tibial thrust: a primary force in the canine stifle. *J. Am. Vet. Med. Assoc.* 1983; 183:456–9.
41. Slocum B, Devine T. Cranial tibial wedge osteotomy: a technique for eliminating cranial tibial thrust in cranial cruciate ligament repair. *J. Am. Vet. Med. Assoc.* 1984; 184:564–9.
42. Souryal TO, Moore HA, Evans JP. Bilaterality in anterior cruciate ligament injuries: associated intercondylar notch stenosis. *Am. J. Sports Med.* 1988; 16:449–54.
43. Sturnick DR, Van Gorder R, Vacek PM, *et al*. Tibial articular cartilage and meniscus geometries combine to influence female risk of anterior cruciate ligament injury. *J. Orthop. Res.* 2014; 32:1487–94.
44. Tapper EM, Hoover NW. Late results after meniscectomy. *J. Bone Joint Surg. Am.* 1969; 51:517–26 passim.
45. Todd MS, Lalliss S, Garcia E, *et al*. The relationship between posterior tibial slope and anterior cruciate ligament injuries. *Am. J. Sports Med.* 2010; 38:63–7.
46. van Eck CF, Martins CA, Vyas SM, *et al*. Femoral intercondylar notch shape and dimensions in ACL-injured patients. *Knee Surg. Sports Traumatol. Arthrosc.* 2010; 18:1257–62.
47. von Porat A, Roos EM, Roos H. High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. *Ann. Rheum. Dis.* 2004; 63: 269–73.
48. Vyas D, Semakula B, Elson LE, Chimes GP. Anterior cruciate ligament tear: surgical reconstruction versus nonsurgical management. *PM R.* 2012; 4: 1006–14.
49. Whitney DC, Sturnick DR, Vacek PM, *et al*. Relationship between the risk of suffering a first-time noncontact ACL injury and geometry of the femoral notch and ACL: a prospective cohort study with a nested case-control analysis. *Am. J. Sports Med.* 2014; 42:1796–805.
50. Wolters F, Vrooijink SH, Van Eck CF, Fu FH. Does notch size predict ACL insertion site size? *Knee Surg. Sports Traumatol. Arthrosc.* 2011; 19(Suppl. 1): S17–21.
51. Zeng C, Gao SG, Wei J, *et al*. The influence of the intercondylar notch dimensions on injury of the anterior cruciate ligament: a meta-analysis. *Knee Surg. Sports Traumatol. Arthrosc*. 2013; 21:804–15.