Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology 22 (2020) 34–38

Contents lists available at ScienceDirect

Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology

journal homepage: www.ap-smart.com

Original Article

Risk factors for noncontact anterior cruciate ligament injury in female high school basketball and handball players: A prospective 3-year cohort study

Junsuke Nakase [a, *], Katsuhiko Kitaoka [b], Yosuke Shima [c], Takeshi Oshima [a], Goro Sakurai [d], Hiroyuki Tsuchiya [a]

[a] Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kanazawa University, Kanazawa, Japan
[b] Department of Orthopaedic Surgery, Kijima Hospital, Kanazawa, Japan
[c] Department of Orthopaedic Surgery, KKR Hokuriku Hospital, Kanazawa, Japan
[d] Division of Rehabilitation, Kanazawa University Hospital, Kanazawa, Japan

ARTICLE INFO

Article history:
Received 20 April 2020
Received in revised form
23 May 2020
Accepted 19 June 2020

ABSTRACT

Introduction: The risk factors of noncontact anterior cruciate ligament (ACL) injury remain an enigma. The purpose of this study was to prospectively evaluate the risk factors for noncontact ACL injury in female high school basketball and handball players.
Materials and Methods: We conducted a 3-year prospective cohort study between 2009 and 2014, and it included 317 female high school athletes aged 15 years. At baseline, they underwent detailed examinations for various parameters that were documented during their first year of high school. The parameters assessed were height (cm), weight (kg), general joint laxity (points), navicular drop (mm), anterior laxity of the knee using the KT-1000 Knee Ligament Arthrometer (mm), angle of femoral anteversion (°), knee extensor/flexor muscle strength (Nm/kg), and hip abductor strength (Nm/kg). All ACL injuries that occurred during these 3 years were recorded.
Results: Of 317 players, 27 were excluded because they either had a history of ACL injury or could not complete the study. Thirty ACL tears occurred. Three of the ACL injuries were contact injuries, whereas the remaining 27 were noncontact injuries. Greater body weight (95% confidence interval [CI], 1.030–1.174; P = 0.004), a high hip abductor strength (95% CI, 1.462–4.827; P = 0.001), and small femoral anteversion (95% CI, 0.746–0.982; P = 0.027) were found to be risk factors in logistic regression analysis.
Conclusion: Greater body weight, a high hip abductor strength, and small femoral anteversion were risk factors for noncontact ACL injury in female high school basketball and handball players.
© 2020 Asia Pacific Knee, Arthroscopy and Sports Medicine Society. Published by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

Anterior cruciate ligament (ACL) injuries are common in young athletes, and they are associated with serious sequelae, including an increased risk of early-onset posttraumatic osteoarthritis, regardless of whether non-surgical or surgical treatment is chosen.[1] In light of recent global research efforts, noncontact ACL injury has become recognized as an injury that may, to some extent, be preventable; consequently, considerable attention has been directed to this field.[2–4] Prospective cohort studies investigating risk factors that may predispose athletes to noncontact ACL injury are a critical step in preventing these injuries.[5] Although various worldwide studies have addressed this subject, a clear consensus has yet to be reached.[6–10] Numerous anatomic ACL injury risk factors have been identified, e.g., an increased lateral posterior tibial slope and narrowing of the intercondylar fossa of the femur.[11,12] Subtalar joint overpronation has been reported to be associated with noncontact ACL injuries.[13] It has been suggested that this may be a product of overpronation increasing anterior translation of the tibia with respect to the femur, thereby increasing the strain on the ACL. Similarly, in the United States (US) and Europe, overpronation of the foot and navicular bone height have been reported as risk factors for ACL injury.[14,15] There is also

* Corresponding author. 13-1 Takaramachi, Kanazawa, 920-8641, Japan.
E-mail address: nakase1007@yahoo.co.jp (J. Nakase).

https://doi.org/10.1016/j.asmart.2020.06.002
2214-6873/© 2020 Asia Pacific Knee, Arthroscopy and Sports Medicine Society. Published by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

evidence of the significant positive association between body weight and ACL injury risk.[16] This may be because the ACL injury risk in athletes is likely to be multifactorial, with injury data from a number of fields demonstrating that numerous physical parameters affect ACL injury rates.

Issues in previous reports examining risk factors for noncontact ACL injury include the following: 1) a lack of consistency in control variables (e.g., sex, age, and type of sports), 2) insufficiency of the sample size, and 3) poor study designs. Additionally, few studies have investigated lower extremity muscle strength (knee extension and flexion).[9]

Female athletes are three to six times more likely to sustain a sports-related noncontact ACL injury than male athletes in comparable high-risk sports.[11,17,18] The ACL injury risk has, in some studies, been reported to be higher in elite sporting contexts than in non-elite sporting contexts.[19] According to a previous report regarding the age distribution of knee injury, the mean age at injury was observed to be 17.0 ± 2.0 years.[20] Therefore, we have focused on highly competitive high-school level female athletes who participate in basketball and handball as a means of investigating risk factors for noncontact ACL injury. To this end, a number of items regarding lower extremity muscle strength (knee extensor, flexor, and hip abductor) were evaluated, in addition to normal anatomical parameters. Of particular interest are factors that can be easily assessed in the school and sports setting. The purpose of this study was to prospectively evaluate the risk factors for noncontact ACL injury in Japanese female high school basketball and handball players. We hypothesized that decreased lower extremity muscle strength; greater joint laxity including overall, the knee, and tarsal bone; and greater femoral anteversion would be risk factors for noncontact ACL injury in female high school basketball and handball players.

Materials and methods

This study included 317 female athletes (all aged 15 years) who participated in highly competitive basketball (eight teams) and handball (seven teams). Participants were recruited over 3 years, from 2009 to 2011. Of these participants, 104 were enrolled in April 2009, 121 in April 2010, and 92 in April 2011. Upon high school enrollment, all participants received a baseline survey, as detailed herein.

Survey items were divided according to anatomical and strength domains. The anatomical assessment included the following variables: height (cm), weight (kg), general joint laxity (points), navicular drop (mm), anterior laxity of the knee (mm), and angle of femoral anteversion (°). The strength assessment included knee extensor/flexor muscle strength (Nm/kg) and hip abductor strength (Nm/kg). General joint laxity was measured according to the method reported by Beighton et al.[21] The navicular drop was measured by marking the outermost part of the navicular bone and measuring the height difference between sitting and standing.[22] Anterior laxity of the knee was assessed using the KT-1000 Knee Ligament Arthrometer (MEDmetric Corp., San Diego, CA, USA) at a pull-out force of 67 N, with measurement of the difference between the left and right sides. The angle of femoral anteversion was examined with the participant in a prone position at 90° of knee joint flexion, with passive internal and external rotations of the hip joint and measurement of the angle formed by a line perpendicular to the tibial bone axis, when the apex of the greater trochanter touched the outermost side.[23]

The maximum knee extension/flexion muscle strength was measured using the MYORET (Kawasaki Heavy Industries, Tokyo, Japan) with both knee joints of participants moving at a constant centripetal velocity at an angle of 60°. Participants warmed up for 10 min on a bicycle ergometer before the start of the measurement. Subsequently, participants assumed a seated position in a chair with 90° of hip flexion, and their trunk, pelvis, and femur were immobilized with a belt. The movement center of the lever arm was matched as accurately as possible to the lateral joint line of the participant's knee, and an arm's length reach was kept between the center of motion and the middle of the lower leg. Resistance pads were fixed to the proximal and distal tibia such that they were equidistant from the arm tip. The knee's range of motion was set as the maximum extension angle from the maximum flexion angle with the participant in a chair-seated position, and the extension/flexion movement of the knee was done thrice in the set range. During the measurement, participants kept their upper limbs crossed, and received standardized verbal explanation and prompting. Measurements were performed three times after an initial practice round to allow the participants to become accustomed to the measurement device and procedure. Values from each measurement round were averaged to give a final maximum muscle strength value. Finally, the final maximum muscle strength value was normalized to the participant's body weight.

Hip abductor strength was measured using a hand-held dynamometer (Micro Total Analysis Systems F-1; ANIMA Corp., Tokyo, Japan). Participants were placed in a supine position on an examination table, and an intermediate hip abduction/adduction position, which served as the measurement start position. Resistance from the hand-held dynamometer was applied 2 cm proximal from the condyle of the femur, and the maximum muscle strength was measured over 2 s. Another examiner held the participant's shoulders and pelvis contralateral to the measurement limb. The test was performed twice on each side, with the mean peak force taken as the final value. A 2-minute break was provided between each measurement. Finally, peak force measurements were normalized to the participant's body weight and length of the lower limb. All measurements of muscle strength were conducted or supervised by proficient orthopedic surgeons and physiotherapists. Each measurement was performed by one examiner during the 3-year period.

This research study received ethical approval from the Kanazawa University Research Committee's Board of Representatives (reference number: 1050), and informed consent was obtained from the participants.

After baseline data were collected, the occurrence of ACL injuries was recorded prospectively for the subsequent 3 years. Coaches were instructed to maintain a continuous log of all data requested, and contacted by telephone and/or e-mail at least once per month to record new injuries, in addition to all playing activities in training and competition. ACL injuries were diagnosed by staff from a medical institution following full physical examination and magnetic resonance imaging, and after direct arthroscopic visualization confirmed a complete ACL tear during subsequent ACL reconstruction.

Data were analyzed using SPSS for Windows 23.0 (IBM Corp., Armonk, NY, USA). The knee extension/flexion muscle strength and hip abductor strength were measured from the affected side in the ACL injury group and randomly from the left or right side in the control group. First, each item was compared using the Student t-test. Second, items with a P-value less than 0.2 were considered as independent variables, and the presence or absence of ACL injury served as the dependent variable for logistic regression analysis (forced entry). Because of multicollinearity in the left/right measurements of the angle of femoral anteversion, knee flexion muscle strength, and hip abductor strength, the affected side was assigned to the ACL injury group, and the left or right side was assigned randomly to the control group. The level of significance for all statistical analyses was set to $P = 0.05$ (P-values <0.05 were considered statistically significant). A prior power analysis for the sample size was performed; for an effect size of 0.76, power of 0.8, and an α level of 0.05, at least 154 individuals were required.

Results

Among the 317 athletes enrolled, 27 athletes had incomplete data because of poor health or a poor condition on the day of the baseline survey, failed to complete the 3-year follow-up, or had a history of ACL injury. Consequently, 290 athletes (186 basketball players, 104 handball players) constituted the final study cohort. Participants' mean height and weight were 161.2 ± 5.9 cm and 55.2 ± 6.3 kg, respectively.

Among the 290 participants, 30 knees from 28 athletes had an ACL injury in the 3 years up to graduation (2 players had bilateral injuries). Of these, 18 injuries occurred during competition and 12 injuries occurred during practice. Basketball and handball accounted for 17 and 13 injuries, respectively. Noncontact injuries were responsible for 27 of the 30 injuries, with the majority (17 injuries) occurring because of rapid cutting and six occurring during jump landings.

Between the group of 25 athletes (27 knees) who had a noncontact ACL injury (ACL group) and the 260 athletes who did not (control group), there was no significant difference in any factors according to the Student t-test (Table 1). When logistic regression analysis was performed for body weight, angle of femoral anteversion, and hip abductor strength, all items exhibited significant differences between the groups (Table 2).

Discussion

The most notable finding of this study was that a high hip abductor strength and small femoral anteversion were risk factors for noncontact ACL injury in female high school basketball and handball players. Interestingly, different results of hip abductor strength were reported by Khayambashi et al.[24]

There have been many reports regarding risk factors for ACL injury from the US and Europe. When the intercondylar fossa of the femur is narrow, there is general joint laxity, knee hyperextension, and high body mass index (BMI), among other predisposing traits.[8,10,25] Greater weight and BMI have been associated with an increased risk of ACL injury.[7,9] In a large cross-sectional study, high body weight had an effect on the risk of ACL injury.[26] In the present study, it was noted that the average weight was greater in the ACL group than in the control group, although very similar heights were observed between the groups. Greater body weight was one of the risk factors for noncontact ACL injury in this cohort.

Hewett et al.[27] conducted three-dimensional motion analysis of two-legged landings in 205 female university athletes, and they reported that nine athletes with an ACL injury had a significantly greater valgus angle of the knee. Consequently, increasing attention has focused on preventing dynamic knee valgus moments during exercise. Numata et al.[28] reported that knee valgus was significantly greater in ACL-injured group than in the control group. The valgus angle of the knee is greatly affected by foot pronation and hip adduction; thus, we focused on the navicular drop and hip abductor strength in our study. Although some studies revealed that over-pronation of the subtalar joint is a risk factor for ACL injury,[23–25] another study suggested that no relationship exists between the two.[29] Even in the context of substantial literature, a consensus has not been reached regarding risk factors for ACL injury, with some studies suggesting that risk factors for noncontact ACL injury are likely multifactorial.[7,30] The navicular drop could not be identified as a risk factor for noncontact ACL injury in the current study.

With regard to the assessment of hip abductor strength, Claiborne et al.[15] conducted a three-dimensional motion analysis of one-legged squatting, with simultaneous measurement of the hip joint and knee joint muscle strength in healthy individuals, and they reported a significant negative correlation between hip abductor strength and the valgus angle of the knee. Khayambashi et al.[24] reported that baseline hip abductor strength measures were significantly lower in noncontact ACL-injured athletes than in noninjured athletes. On the basis of biomechanical principles and current studies, weakness in hip abductor strength is suggested to be a predisposing risk factor for noncontact ACL injury. We expected and hypothesized that decreased hip abductor strength would be associated with a subsequent noncontact ACL injury in our study. We observed that a high hip abductor strength was a risk factor for noncontact ACL injury, which negates our hypothesis. Our findings are supported by a recent study by Steffen et al.,[31] who reported a borderline association between greater hip abductor strength and ACL rupture. The difference between Khayambashi

Table 1
Comparison of the anatomical and strength assessments between the ACL group and control group.

	Risk factor	ACL group	Control group	P-value
Anatomical Assessment	Height (cm)	161.3 ± 7.0	161.3 ± 5.9	0.98
	Body weight (kg)	57.3 ± 7.1	55.2 ± 6.4	0.12
	General joint laxity (point)	2.3 ± 2.0	2.6 ± 2.2	0.47
	Navicular drop (mm)	8.4 ± 4.8	8.3 ± 3.6	0.82
	Anterior laxity of the knee (mm)	3.7 ± 1.1	4.0 ± 1.4	0.28
	Femoral anteversion (°)	15.3 ± 3.3	16.6 ± 3.5	0.07
Strength Assessment	Knee extension strength (Nm/kg)	1.5 ± 0.5	1.6 ± 0.3	0.54
	Knee flexion strength (Nm/kg)	0.9 ± 0.3	0.9 ± 0.2	0.99
	Hip abduction strength (Nm/kg)	1.3 ± 0.3	1.3 ± 0.2	0.13

ACL, Anterior cruciate ligament.
Data are presented as a mean ± standard deviation unless otherwise indicated.

Table 2
Risk factors for noncontact ACL injury according to logistic regression analysis.

	Standard partial regression coefficient	SE	P-value	Odds ratio	95% confidence interval
Body weight	0.095	0.033	0.004	1.100	1.030–1.174
Femoral anteversion	−0.156	0.070	0.027	0.856	0.746–0.982
Hip abduction strength	0.977	0.305	0.001	2.656	1.462–4.827

ACL, Anterior cruciate ligament; SE, Standard error.

et al.'s study and ours and Steffen et al.'s study is due to sex. Although Khayambashi et al.'s study was very interesting, it combined men and women as study subjects, which was a crucial limitation. In studies that indicated that high hip abductor strength was associated with ACL tear included, only young female athletes were included. Vacek et al.[32] conducted a matched case-control study to determine the relationship between ACL tear and lower muscle strength in a group of young athletes. They reported that low hip abductor strength was not associated with the risk of ACL injury in multivariate analysis. Although hip abductor strength was measured twice on each side, with the mean peak force used as the final value and measured by a single examiner, we did not check test-retest reliability. Thus, these results should be interpreted with caution.

Uhorchak et al. investigated the strength of the knee extensors and flexors using concentric and eccentric isokinetic testing as a means of identifying risk factors for ACL injury.[9] They examined several strength ratios, including those thought to be more specific to the ACL injury pattern, but none was determined to be a significant factor; this result is consistent with our findings. In theory, ACL loads are generated during sudden changes of direction, jumping, and landing. There was no significant association between peak strength and ACL injury in our study. However, this does not necessarily mean that we should stop focusing on the role of muscles in the mechanism of ACL injury. It can be speculated that muscle activation patterns rather than strength could differ between injured and uninjured athletes. We should focus on timing of muscle activation rather than on peak strength. This hypothesis needs to be confirmed in another study.

Femoral rotational abnormalities increase one's susceptibility to an ACL tear. Amraee et al. investigated the relationship between hip anteversion and ACL tear,[33] and they found a positive correlation between hip anteversion and the risk of ACL tear. An increase in hip anteversion by 1° corresponds to an increase in the probability of ACL injury by 1.78. In theory, increased femoral anteversion occurs with hip internal rotation and knee valgus alignment during landing and cutting motion, and it is considered a risk factor for ACL injury.[34] We also expected that large femoral anteversion would be a risk factor for ACL tear. In the present study, small femoral anteversion was indicated as a risk factor for noncontact ACL injury. The mean difference between the two groups was only 1.3°, and this difference has no clinical significance. In addition, we used the Craig test, and there may have been a problem with the measurement method. Some studies have investigated the relationship between the Craig test and computed tomography (CT) or magnetic resonance imaging (MRI).[35–37] Boster et al. compared three measurement methods (MRI, CT, and the Craig test) for femoral anteversion and concluded that the diagnosis should not rely on the range of motion of the hip joint. Further, Souza et al. reported that in persons with a low BMI, the clinical test to assess femoral anteversion was shown to exhibit substantial reliability but only moderate agreement with MRI measurements. Thus, the Craig test may have influenced these results. Further research is needed in the future to confirm this.

The strengths of this study include its prospective study design, large sample size and injury rate of ACL injury, focus on adolescent, female high school basketball and handball players, high follow-up rate, and confirmation of a complete ACL tear with direct arthroscopic visualization. However, several limitations exist. First, we were unable to record exposure data for each individual player; therefore, we were unable to correct for exposure in the risk factor analyses. It is assumed that players receiving a greater amount of active time would be more likely to become injured due to increased playing exposure. Moreover, we could not evaluate each player's individual performance level. Second, our study was limited by the fact that our data were collected prospectively from a single time. We cannot rule out the possibility that athletes' muscle strength may have changed between the time of data collection and injury. Third, we used a hand-held dynamometer to measure hip abductor strength, but an isokinetic testing machine may have provided more reliable values.

Conclusion

Greater body weight, a high hip abductor strength, and small femoral anteversion were risk factors for noncontact ACL injury in female high school basketball and handball players.

Funding/Support Statement

This research was supported by the grants of Japan Orthopaedics and Traumatology Research Foundation, Inc. No. 286.

Declaration of competing interest

The authors declare that they have no conflicts of interests.

Acknowledgments

Statistical analysis was supervised by Hiyoyuki Nakamura MD, PhD (Department of Environmental and Preventive Medicine).

References

1. Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med*. 2007 Oct;35(10):1756–1769.
2. Dragoo JL, Braun HJ, Durham JL, Chen MR, Harris A. Incidence and risk factors for injuries to the anterior cruciate ligament in national collegiate athletic association football. *Am J Sports Med*. 2012 May;40(5):990–995.
3. Hewett TE, Ford KR, Myer GD. Anterior cruciate ligament injuries in female athletes: Part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *Am J Sports Med*. 2006 Mar;34(3):490–498.
4. Stevenson JH, Beattie CS, Schwartz JB, Busconi BD. Assessing the effectiveness of neuromuscular training programs in reducing the incidence of anterior cruciate ligament injuries in female athletes: a systematic review. *Am J Sports Med*. 2015 Feb;43(2):482–490.
5. Bahr R, Krosshaug T. Understanding injury mechanisms: a key component of preventing injuries in sport. *Br J Sports Med*. 2005 Jun;39(6):324–329.
6. 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 May;42(5):1039–1048.
7. Hewett TE, Myer GD, Ford KR. Anterior cruciate ligament injuries in female athletes: Part 1, mechanisms and risk factors. *Am J Sports Med*. 2006 Feb;34(2): 299–311.
8. Sundemo D, Hamrin Senorski E, Karlsson L, et al. Generalised joint hypermobility increases ACL injury risk and is associated with inferior outcome after ACL reconstruction: a systematic review. *BMJ Open Sport Exerc Med*. 2019 Nov;5(1), e000620.
9. Uhorchak JM, Scoville CR, Williams GN, Arciero RA, St Pierre P, Taylor DC. Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point cadets. *Am J Sports Med*. 2003 Nov-Dec;31(6):831–842.
10. Stanley LE, Kerr ZY, Dompier TP, Padua DA. Sex differences in incidence of anterior cruciate ligament, medial collateral ligament, and meniscal injuries in collegiate and high school sports: 2009-2010 through 2013-2014. *Am J Sports Med*. 2016 Jun;44(6):1565–1572.
11. Bayer S, Meredith SJ, Wilson K, et al. Knee morphological risk factors for anterior cruciate ligament injury: a systematic review. *J Bone Joint Surg Am*. 2020 Apr;102(8):703–718.
12. Bojicic KM, Beaulieu ML, Imaizumi Krieger DY, Ashton-Miller JA, Wojtys EM. Association between lateral posterior tibial slope, body mass index, and ACL injury risk. *Orthop J Sports Med*. 2017 Feb;5(2), 2325967116688664.
13. Trimble MH, Bishop MD, Buckley BD, Fields LC, Rozea GD. The relationship between clinical measurements of lower extremity posture and tibial translation. *Clin Biomech*. 2002 May;17(4):286–290.
14. Allen MK, Glasoe WM. Metrecom measurement of navicular drop in subjects with anterior cruciate ligament injury. *J Athl Train*. 2000 Oct;35(4):403–406.
15. Claiborne TL, Armstrong CW, Gandhi V, Pincivero DM. Relationship between hip and knee strength and knee valgus during single leg squat. *J Appl Biomech*.

2006 Feb;22(1):41–50.
16. Evans KN, Kilcoyne KG, Dickens JF, et al. Predisposing risk factors for non-contact ACL injuries in military subjects. *Knee Surg Sports Traumatol Arthrosc*. 2012 Aug;20(8):1554–1559.
17. Mihata LC, Beutler AI, Boden BP. Comparing the incidence of anterior cruciate ligament injury in collegiate lacrosse, soccer, and basketball players: implications for anterior cruciate ligament mechanism and prevention. *Am J Sports Med*. 2006 Jun;34(6):899–904.
18. Gornitzky AL, Lott A, Yellin JL, Fabricant PD, Lawewnce JT, Ganley TJ. Sport-specific yearly risk and incidence of anterior cruciate ligament tears in high school athletes: a systematic review and meta-analysis. *Am J Sports Med*. 2016 Oct;44(10):2716–2723.
19. Waldén M, Hägglund M, Magnusson H, Ekstrand J. Anterior cruciate ligament injury in elite football: a prospective three-cohort study. *Knee Surg Sports Traumatol Arthrosc*. 2011 Jan;19(1):11–19.
20. de Loës M, Dahlstedt LJ, Thomée R. A 7-year study on risks and costs of knee injuries in male and female youth participants in 12 sports. *Scand J Med Sci Sports*. 2000 Apr;10(2):90–97.
21. Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. *Ann Rheum Dis*. 1973 Sep;32(5):413–418.
22. Shultz SJ, Carcia CR, Gansneder BM, Perrin DH. The independent and interactive effects of navicular drop and quadriceps angle on neuromuscular responses to a weight-bearing perturbation. *J Athl Train*. 2006 Jul-Sep;41(3):251–259.
23. Ruwe PA, Gage JR, Ozonoff MB, DeLuca PA. Clinical determination of femoral anteversion. A comparison with established techniques. *J Bone Joint Surg Am*. 1992 Jul;74(6):820–830.
24. Khayambashi K, Ghoddosi N, Straub RK, Powers CM. Hip muscle strength predicts noncontact anterior cruciate ligament injury in male and female athletes: a prospective study. *Am J Sports Med*. 2016 Feb;44(2):355–361.
25. Loudon JK, Jenkins W, Loudon KL. The relationship between static posture and ACL injury in female athletes. *J Orthop Sports Phys Ther*. 1996 Aug;24(2):91–97.
26. Thein R, Hershkovich O, Gordon B, et al. The prevalence of cruciate ligament and meniscus knee Injury in young adults and associations with gender, body mass index, and height a large cross-sectional study. *J Knee Surg*. 2017 Jul;30(6):565–570.
27. Hewett TE, Ford KR, Hoogenboom BJ, Myer GD. Understanding and preventing acl injuries: current biomechanical and epidemiologic considerations - update. *N Am J Sports Phys Ther*. 2010 Dec;5(4):234–251.
28. Numata H, Nakase J, Kitaoka K, et al. Two-dimentsional motion analysis of dynamic knee valgus identifies female high school athletes at risk of non-contact anterior cruciate ligament injury. *Knee Surg Sports Traumatol Arthrosc*. 2018 Feb;26(2):442–447.
29. Smith J, Szczerba JE, Arnold BL, Perrin DH, Martin DE. Role of hyperpronation as a possible risk factor for anterior cruciate ligament injuries. *J Athl Train*. 1997 Jan;32(1):25–28.
30. Myklebust G, Maehlum S, Holm I, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med*. 2003 Mar;13(2):71–78.
31. Steffen K, Nilstad A, Kristianslund EK, Myklebust G, Bahr R, Krosshaug T. Association between lower extremity muscle strength and noncontact ACL injuries. *Med Sci Sports Exerc*. 2016 Nov;48(11):2082–2089.
32. Vacek PM, Slauterbeck JR, Tourville TW, et al. Multivariate analysis of the risk factors for first-time noncontact ACL injury in high school and college athletes: a prospective cohort study with a nested, matched case-control analysis. *Am J Sports Med*. 2016 Jun;44(6):1492–1501.
33. Amraee D, Alizadeh MH, Minoonejhad H, Razi M, Amraee GH. Predictor factors for lower extremity malalignment and non-contact anterior cruciate ligament injuries in male athletes. *Knee Surg Sports Traumatol Arthrosc*. 2017 May;25(5):1625–1631.
34. Alpay Y, Ezici A, Kurk MB, Ozyalvac ON, Akpinar E, Bayhan AI. Increased femoral anteversion related to infratrochanteric femoral torsion is associated with ACL rupture. *Knee Surg Sports Traumatol Arthrosc*. 2020 Feb. https://doi.org/10.1007/s00167-020-05874-0 [Epub ahead of print].
35. Muhamad AR, Freitas JM, Bomar JD, Dwek J, Hosalkar HS. CT and MRI lower extremity torsional profile studies: measurement reproducibility. *J Child Orthop*. 2012 Oct;6(5):391–396.
36. Botser IB, Ozoude GC, Martin DE, Siddiqi AJ, Kuppuswami S, Domb BG. Femoral anteversion in the hip: comparison of measurement by computed tomography, magnetic resonance imaging, and physical examination. *Arthroscopy*. 2012 May;28(5):619–627.
37. Souza RB, Powers CM. Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. *J Orthop Sports Phys Ther*. 2009 Jan;39(1):12–19.