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. 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. Prospective cohort studies investigating risk factors that may predispose athletes to noncontact ACL injury are a critical step in preventing these injuries. Although various worldwide studies have addressed this subject, a clear consensus has yet to be reached. 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. Subtalar joint overpronation has been reported to be associated with noncontact ACL injuries. 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. There is also

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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 (º), 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 (º), knee extensor/flexor muscle strength (Nm/kg), and hip abductor strength (Nm/kg). All ACL injuries that occurred during these 3 years were recorded.

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.

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evidence of the significant positive association between body weight and ACL injury risk. 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). 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. The ACL injury risk has, in some studies, been reported to be higher in elite sporting contexts than in non-elite sporting contexts. 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. 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 anteverision 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.

Study 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 anteverision (°). 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. The navicular drop was measured by marking the outermost part of the navicular bone and measuring the height difference between sitting and standing. 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 anteverision 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. The maximum knee extension/flexion muscle strength was measured using the MVORET (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 anteverision, 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 \( \alpha \) 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 \( 161.2 \pm 5.9 \) cm and \( 55.2 \pm 6.3 \) 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 and small femoral anteversion were risk factors for noncontact ACL injury in female high school basketball and handball players. 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.

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### Table 1

| 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 (º) | 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 factor           | 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. 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.

Uhoroachk 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. 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 start 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, 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. 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), but 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.

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Declaration of competing interest

The authors declare that they have no conflicts of interests.

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