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Original Article

Lower hamstring to quadriceps muscle strength ratio and lower body weight as factors associated with noncontact anterior cruciate ligament injury in male American football players: A prospective cohort study

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A R T I C L E I N F O

Keywords:
Collegiate American football player
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Risk factor

A B S T R A C T

Background: Previous studies have aimed to determine the use of certain risk factors in predicting the occurrence of noncontact anterior cruciate ligament (ACL) injuries. Unfortunately, evidence regarding noncontact ACL injuries in male American football players is limited. This prospective cohort study aimed to identify intrinsic risk factors for noncontact ACL injury among male American football players.
Methods: This study evaluated 152 male American football players in Japan for potential noncontact ACL injury risk factors during a preseason medical assessment, including anthropometric, joint laxity, and flexibility, muscle flexibility, muscle strength, and balance measurements. A total of 25 variables were examined. Participants were monitored during each season for noncontact ACL injury, as diagnosed by physicians.
Results: Noncontact ACL injuries occurred in 11 knees of 11 players (prevalence; 7.1 %). Injured players were significantly more likely to have lightweight ($P = 0.049$). No statistically significant between-group differences were found for any other variables. Participants with a lower hamstring to quadriceps (H/Q) ratio ($P = 0.04$) were more likely to sustain noncontact ACL injuries.
Conclusion: Lower H/Q ratio and lower body weight were significantly associated with new-onset noncontact ACL injury in male American football players. These findings will help develop strategies to prevent noncontact ACL injuries in male American football players.

1. Introduction

Anterior cruciate ligament (ACL) injuries are more likely to occur in sports, involving cutting, jumping, pivoting, accelerating, and decelerating motions. ACL injuries are more common in American football among male athletes. The overall one-season injury risk of a National Football League player sustaining an ACL injury was 1.9 %.[1] Previous studies revealed that only less than two-thirds of American football players return to professional football[2], and those who return perform at a lower level[3] and have a shorter career.[4] Therefore, reducing ACL injury in American football players is of considerable interest.

Several risk factors increase the likelihood of sustaining ACL injury. Intrinsic risk factors for male athletes include general joint laxity[5], bony anatomies[5–7], decreased fatigue resistance[8], decreased hip abductor strength[9], and decreased hip external rotational strength.[9] These pieces of evidence are created from studies about several sports such as soccer, handball, basketball, volleyball, etc.[8,9] A few prospective cohort studies were conducted on ACL injury risk for American football players. To date, video analyses of injured players and data on risk by position and ground surface exist[10,11], but very few data exist on intrinsic risk factors in American football players for ACL injury prevention.

The mechanisms of ACL injury in American football were classified as contact and noncontact injuries. ACL injuries from direct knee contact are difficult to prevent. Conversely, noncontact injuries, including those caused by indirect contact, may be preventable if risk factors are identified. Surprisingly, noncontact injuries account for 70%–73 % of ACL

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injuries in American football players although contact injuries were previously thought as the most common type of ACL injury.[10,11]

American football, unlike other ball sports, features specialized player roles, varied body types, and helmets that can limit the field of vision. These factors may lead to unique noncontact ACL injury risks. However, research on American football is scarce. Therefore, this study aimed to identify intrinsic risk factors for noncontact ACL injuries in male American football players. This study hypothesized that noncontact ACL injury risks in American football differ from those in other sports.

2. Materials and methods

This prospective cohort study examined male collegiate American football players during the 2018–2019 season. Risk factor data were collected during a preseason medical assessment. All participants were subsequently monitored for injuries during two football seasons (2 years). This study was a part of the Prospective Study of Predictors of Sports Injuries: UTokyo Sports Science Institute Sports Injury Prevention Project.[12,13] Our institution's ethics committee approved the protocol, and all participants provided written consent.

This study included 155 male American football players from one collegiate team in Japan. We included American football players who provided informed consent and excluded players who were lost to follow-up during the injury registration period, those with histories of ACL injuries, and players with musculoskeletal injuries documented during the medical assessment or within the preceding three months. None of the players were injured at the start of the study, and none reported a history of lower limb musculoskeletal injuries over the preceding 3 months. We enrolled 154 players with an average of 2.2 years of American football experience (range: 0–8 years). All participants received preseason medical checkups and completed a questionnaire that collected data on age, injury history, and medication. Preseason data from five physical screening tests were used, including anthropometric measurements, joint laxity, joint range of motion (ROM), muscle flexibility, muscle strength, and balance. Each participant's ACL injury history was recorded, starting immediately after informed consent and continuing until the season's completion. Consequently, only one set of measurement data was generated by each player. The latest data were used for players participating in the medical assessment more than once. No participants were lost to follow-up during the injury registration period.

2.1. Anthropometric measurements

Body weight and height were measured for each player at the preseason medical checkup, and body mass index (BMI) was calculated from these variables. InBody 270 (Biospace Co., Ltd., Seoul, Korea), which is a multifrequency impedance analyzer that can record each player's lean soft tissue mass (skeletal muscle mass), body fat mass, and percentage body fat, was used to measure each body composition parameter. Additionally, the height of each player's navicular tubercle was measured as a flat-foot index.

2.2. Joint laxity and flexibility

2.2.1. General joint laxity testing

Each player underwent general joint laxity testing using methods from the University of Tokyo, as described by Watanabe et al.[14] The test consisted of seven conditions: thumb-to-forearm position, elbow hyperextension of ≥15°, shoulder hyper-rotation, hip hyper–external rotation of ≥90° while standing, knee hyperextension of ≥10°, ankle hyper-dorsiflexion at ≥45° of knee flexion, and trunk flexion with both palms touching the floor and knees fully extended. Shoulder hyper-rotation was considered positive when participants could clasp their hands from both the cranial and caudal sections of their back. Hip hyper–external rotation was considered positive when participants could maintain their hips at 90° of external rotation with both legs in a neutral position. All tests, except for trunk flexion, and hip external rotation, were bilaterally performed. A point value of 0.5 was given each time a player surpassed the designated laxity measurement on both the right and left sides of the tested joints (wrists, elbows, shoulders, knees, and ankles) and one point each was given for the trunk and hip, for a maximum possible score of seven points.

2.2.2. Joint ROM

Joint ROM was measured for internal hip rotation, ankle dorsiflexion, and knee extension based on previous studies.[15,16] The passive hip internal rotation angle in the prone position served as the measure of internal hip rotation. The weight-bearing ankle dorsiflexion angle with knee flexion served as the measure of ankle dorsiflexion. The knee hyperextension angle was measured in a standing position with the quadriceps engaged for knee extension.

2.2.3. Muscle flexibility

Muscle flexibility tests were performed on the iliopsoas, quadriceps femoris, hamstring, gastrocnemius, and soleus muscles bilaterally using previously described methods.[17]

2.2.3.1. Iliopsoas. The iliopsoas was measured by determining the hip joint angle when the participants passively bent their opposite hip joint to the maximum with their hands in a supine position.

2.2.3.2. Quadriceps. The participant grasped her lower leg proximal to the ankle and pulled it toward the buttocks to measure quadriceps flexibility. The quadriceps muscle measurement was performed by bending knee joint while in a prone position. The examiner verbally instructed the participants not to engage their buttocks during the measurement.

2.2.3.3. Hamstrings. Hamstring muscle flexibility was measured with the hip at 90° of flexion in a supine position. A researcher measured the angle between the vertical line to the floor while holding the participant's heel, and the long axis of the tibia after the knee joint was maximally extended.

2.2.3.4. Gastrocnemius. The ankle joint's active dorsiflexion angle during maximum dorsiflexion was measured in the supine position, with the knee extended, and maintained in a neutral position relative to the varus-valgus angle of the ankle.

2.2.3.5. Soleus. The ankle joint's active dorsiflexion angle was measured when maximally dorsiflexed in the prone position with the knee at 90° of flexion.

2.3. Muscle strength tests

2.3.1. Isometric knee extension and flexion

Cybex Humac Norm (CSMi, MA, USA) was used to measure isometric muscle strength during knee flexion and extension. The player used a stationary exercise bicycle for 5 min before the measurement. The measurement order was randomized. The test comprised isometric contraction with knee flexion and extension at 70°. The highest peak torque value was recorded. Strength measures were normalized to body weight. Further, the hamstring to quadriceps (H/Q) muscle strength ratio was calculated (Fig. 1).

2.3.2. Isometric hip abduction

Hip abductor strength was isometrically measured using a handheld dynamometer (μTAS F-1; Anima Industry Inc). Each participant was instructed to lay in a supine position with neutral hips next to a wall,

Fig. 1. Knee extension and flexion strength testing.

with both knees extended, and arms crossed over her chest. The peak force generated as the participants abducted their legs maximally over 5 s, with 1 min of rest between contractions was recorded. The dynamometer was placed on the lateral epicondyle of the femur, and the distance between the lateral epicondyle and the hip center was measured. Isometric assessments of hip abductor strength using a handheld dynamometer have excellent intra- and intertester reliability.[18] The highest peak torque value was recorded. Strength measures were recorded as normalized to body weight.

2.4. Balance tests

Double- and single-leg stance balance using a 1-m Footscan pressure plate with 8192 resistive sensors and a pixel resolution of 5.08 × 7.62 mm (RSscan International) were measured, with a sampling frequency of 250 Hz, as per previously described methods.[19,20] First, a participant performed a 30-s trial of double-leg standing balance barefooted with the arms crossed over the chest and eyes open. Each participant performed a 30-s trial of single-leg standing balance, similar to the double-leg standing balance test but alternating left and right legs, after a 30-s rest interval. The total distance of the center of pressure during the 30 s in both tests was considered the balance parameter.[21]

2.5. ACL injury diagnosis

ACL injury was directly diagnosed by an orthopaedic team physician. The diagnosis (e.g., ACL injury), date of injury, site (e.g., left knee), and the mechanism of injury (contact or noncontact) were documented for every injury. Direct contact with the lower extremity is considered a contact mechanism, while indirect contact (contact not involving the injured knee/lower extremity) and no contact were considered noncontact mechanisms. The mechanism of injury was determined by video analysis. Both physical examination and magnetic resonance imaging diagnosed an injury. Injuries were only considered during American football practice or game.

2.6. Statistical analysis

All statistical analyses were performed using the BellCurve for Excel (SSRI Co., Ltd., Tokyo, Japan). Parameters—except for lower limb parameters—were compared between injured and uninjured players. Additionally, lower limb parameters were compared between the injured players' injured limbs and the limb mean from uninjured players. The unpaired two-tailed Student *t*-test and Mann-Whitney *U* test were used to assess continuous and nonparametric variables, respectively. *P*-values of <0.05 were considered statistically significant. A post-hoc power analysis of the significant risk factors, namely weight (effect size: 0.62) and H/Q ratio (effect size: 0.65), yielded a power of 1.00 for both, calculated at an α level of 0.05.

3. Results

ACL injuries occurred in 13 knees of 13 players (prevalence: 8.4 %). Of the 13 players, 2 and 11 had contact injuries and noncontact (prevalence: 7.1 %) ACL injuries. Hence, a total of 152 players (11 injured and 141 uninjured players) were analyzed. Table 1 displays the distribution of positions among players. Of the 11 injured players, 6 sustained ACL injuries in the dominant leg and 5 in the non-dominant leg. Table 2 presents data on the injured and uninjured groups, and Table 3 compares injured and uninjured players' anthropometric measurements, joint laxity tests, and double-leg stance balance test results. Injured players were significantly more likely to have lightweight ($P = 0.049$). No statistically significant between-group differences were found for any other variables. Table 4 compares lower limb parameters between the injured and uninjured players. Participants with a lower H/Q ratio ($P = 0.04$) were more likely to sustain noncontact ACL injuries.

4. Discussion

The most important finding in this study was that a lower H/Q ratio and lower body weight were significantly associated with new-onset noncontact ACL injury in male American football players. In American football, known for its specialized positions and diverse player physiques, the H/Q ratio was identified as a risk factor for noncontact ACL injury, similar to other ball games. This is the first prospective cohort study to show that a lower H/Q ratio is one of the intrinsic risk factors for noncontact ACL injury in male American football players.

The current study revealed a lower H/Q ratio as a factor associated with noncontact ACL injury. Several studies have investigated the association between ACL injury risk and the H/Q ratio. Three studies have examined female athletes[22–24] and two studies have examined both male and female athletes[25] or military cadets[5], but none revealed an association between ACL injury and H/Q ratio. A recent systematic review concluded that the H/Q ratio has limited value for predicting ACL injuries.[26] However, Myer et al. revealed that the H/Q ratio of female athletes with noncontact ACL injuries tended to be smaller than that of donated uninjured female athletes in their studies of female soccer and basketball players. No studies have been conducted on male athletes or American football players. Several video analyses revealed that noncontact ACL injury occurred with the hip flexion and internal rotation with the knee close to full extension.[27,28] The relative hamstring weakness may make them more prone to knee extension and hip flexion position during landing. However, this is only speculation because this

Table 1
Distribution of positions in American football.

Positions (N = 152)	Injured players (n = 11)	Uninjured players (n = 141)
Defensive Back	2	29
Linebacker	5	25
Linemen	1	33
Quaterback	0	9
Running Back	2	20
Tight End	0	2
Wide Receiver	1	23

Data are presented as the number of players.

Table 2
Characteristics of injured and uninjured players.

Demographic profile (N = 152)	Injured players (n = 11)	Uninjured players (n = 141)	*P*-value
Age, y	19.4 ± 0.8	20.1 ± 1.2	0.07
Weight, kg	75.5 ± 3.9	82.6 ± 11.7	0.049*
Height, cm	172.4 ± 3.0	174.8 ± 5.6	0.15
Body mass index, kg/m^2	25.4 ± 1.5	26.9 ± 1.6	0.14

Data are presented as mean ± standard deviation.
* indicates a statistically significant difference ($P < 0.05$).

Table 3
Anthropometric, joint laxity, and double-leg balance measurements between the injured and uninjured groups.

Variables (N = 152)	Injured players (n = 11)	Uninjured players (n = 141)	*P*-value
Anthropometric measurements			
Body muscle mass, kg (lean soft tissue mass)	58.2 ± 4.0	61.9 ± 7.1	0.09
Body fat mass, kg	14.0 ± 3.3	16.6 ± 6.8	0.21
Percentage body fat, %	18.1 ± 4.1	19.7 ± 5.8	0.37
General joint laxity test score (out of 7)	1.5 (0–3.5)	1.0 (0–5.0)	0.95
Balance test for double-leg stance, COP, mm	39.0 ± 23.6	43.4 ± 24.2	0.56

COP: center of pressure. Data are presented as mean ± standard deviation or median (range).
* indicates a statistically significant difference ($P < 0.05$).

Table 4
Lower limb parameters in the injured limb compared with the uninjured limb of both injured and uninjured players.

Variables (N = 152)	Injured limb (n = 11)	Uninjured players mean of both limbs (n = 141)	*P value*
Anthropometric measurement			
Height of navicular tubercle, cm	4.9 ± 0.3	4.9 ± 0.6	0.74
Joint ROM, deg			
Knee extension angle	1.3 ± 3.5	1.2 ± 4.9	0.98
Ankle dorsal flex angle	42.1 ± 6.0	40.7 ± 6.0	0.45
Hip internal rotation angle	36.7 ± 11.0	36.2 ± 8.5	0.85
Muscle flexibility tests results			
Iliopsoas muscle flexibility	6.7 ± 2.4	7.4 ± 3.2	0.47
Quadriceps muscle flexibility	33.8 ± 7.7	33.9 ± 7.7	0.96
Hamstring muscle flexibility	19.9 ± 7.2	20.4 ± 8.5	0.84
Gastrocnemius muscle flexibility	12.3 ± 4.6	11.3 ± 4.3	0.47
Soleus muscle flexibility	21.0 ± 6.6	20.0 ± 5.4	0.54
Muscle strength tests			
Normalized isometric knee extension, N·m/kg	3.2 ± 0.5	3.0 ± 0.5	0.24
Normalized isometric knee flexion, N·m/kg	1.4 ± 0.3	1.5 ± 0.3	0.31
Normalized isometric hip abduction, N·m/kg	2.2 ± 0.3	2.2 ± 0.4	0.83
H/Q ratio	0.45 ± 0.12	0.51 ± 0.09	0.04*
Balance test			
COP in single-leg balance, mm	469.6 ± 120.4	498.3 ± 137.1	0.50

COP: center of pressure; H/Q: hamstring to quadriceps. Data are presented as mean ± standard deviation.
* indicates a statistically significant difference ($P < 0.05$).

study did not involve video analysis. A sub-analysis comparing the H/Q ratio between the injured and non-injured limbs in ACL-injured players revealed an asymmetry with the injured side being smaller, although not significantly different, 0.45 ± 0.12 for the injured side and 0.51 ± 0.11 for the non-injured side ($p = 0.25$). A study for collegiate male American football players reported asymmetry of the H/Q rati.o in football players, which may cause lower extremity sports injury.[29] Asymmetry of the H/Q ratio among the same players may be a risk for ACL injury; thus, training to increase the H/Q ratio and eliminate asymmetry may help prevent ACL injuries. This study additionally investigated the H/Q ratio asymmetry in players with noncontact ACL injuries. We found that the injured side had a marginally lower H/Q ratio (0.45 ± 0.12) compared to the uninjured side (0.51 ± 0.11); however, this difference was not statistically significant (p = 0.25). For players without an ACL injury, the H/Q ratios were consistent on both the right (0.52 ± 0.11) and left sides (0.51 ± 0.14), indicating no asymmetry. These results suggest that H/Q ratio asymmetry may be a significant predictor of ACL injury risk. Nonetheless, further research including large number of players is required to confirm these findings.

The current study revealed that lower body weight was significantly associated with new-onset noncontact ACL injury in male American football players. No significant differences were found in body height, BMI, or body muscle mass other than body weight, but a smaller body size may be more likely to sustain an ACL injury in this study. This may be due to positional factors rather than small body size itself being a risk for ACL injury. Previous studies have reported that noncontact ACL injury risk is higher at positions, such as defensive back, wide receiver, tight end, linebacker, and running back, while linemen have a lower frequency of ACL injuries.[1,30] Players at non-line positions are smaller than linemen. This study revealed that five linebackers, two defensive backs, two running backs, and one wide receiver sustained ACL injuries, while only one lineman suffered from ACL injuries. Brophy et al. reported that American football players with larger BMIs were more likely to suffer contact ACLs, while players with smaller BMIs were more likely to suffer noncontact ACL injuries.[10] These reports are consistent with the present study and support that position and ACL injury are related in American football players. Hence, applying a noncontact ACL injury prevention program to so-called skill position players other than linemen, who are considered at high risk of ACL injury may be effective in American football.

This study revealed that neither general joint laxity[5] nor decreased hip abductor strength[9], which are known risks for ACL injury in male athletes, were associated with new noncontact ACL injury occurrence. However, noncontact ACLs is small (11 players), thus study results cannot conclude that general joint laxity or decreased hip abductor strength are not risks for noncontact ACL injuries in male football players. Further large prospective cohort studies are needed.

For preventing ACL injuries in American football, achieving strength balance between the quadriceps and hamstrings is crucial. Training should target not only the quadriceps and but also hamstrings concurrently. This is especially pertinent for players in running positions in American football.

This study has several limitations. First, the study results are not generalizable to all American football players because the number of participants in this study is not large enough and our study cohort comprised a convenience sample of only one colligate team. However, this study provides valuable knowledge because only a few prospective cohort studies were conducted on American football players. Second, multivariate analysis was not performed in this study. Two risk factors were identified from the univariate analysis. More than 20 incidents of noncontact ACL injury would be needed to perform a multivariate analysis of these two factors. Currently, data on ACL injury incidents are insufficient to conduct the multivariate analysis, and statistical power is also insufficient to perform this analysis. Third, extrinsic factors, such as the surface of the pitch, etc., which may have influenced ACL occurrence were not evaluated. Lastly, the condition of players at the time of injury may differ from their condition at the time of measurement.

5. Conclusion

Lower H/Q ratio and lower body weight were significantly associated with new-onset noncontact ACL injury in male American football players. These findings will help develop strategies to prevent noncontact in male American football players.

Ethical statement

Ethics approval number is 11907-(7).

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Declaration of competing interest

The authors declare that they have no conflict of interest.

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