Hip Muscle Strength Predicts Noncontact Anterior Cruciate Ligament Injury in Male and Female Athletes: A Prospective Study

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Am J Sports Med published online December 8, 2015
DOI: 10.1177/0363546515616237

Hip Muscle Strength Predicts Noncontact Anterior Cruciate Ligament Injury in Male and Female Athletes

A Prospective Study

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Background: Prospective studies have reported that abnormal movement patterns at the trunk, hip, and knee are associated with noncontact anterior cruciate ligament (ACL) injuries. Impaired hip strength may underlie these abnormal movement patterns, suggesting that diminished hip strength may increase the risk of noncontact ACL injury.

Purpose: To determine whether baseline hip strength predicts future noncontact ACL injury in athletes.

Study Design: Case-control study; Level of evidence, 3.

Methods: Before the start of the competitive season, isometric hip strength (external rotation and abduction) was measured bilaterally by use of a handheld dynamometer in 501 competitive athletes (138 female and 363 male athletes) participating in various sports. During the sport season, ACL injury status was recorded, and injured athletes were further classified based on the mechanism of injury (noncontact vs contact). After the season, logistic regression was used to determine whether baseline hip strength predicted future noncontact ACL injury. Receiver operating characteristic (ROC) curves were constructed independently for each strength measure to determine the clinical cutoff value between a high-risk and low-risk outcome.

Results: A total of 15 noncontact ACL injuries were confirmed (6 females, 9 males), for an overall annual incidence of 3.0% (2.5% for males, 4.3% for females). Baseline hip strength measures (external rotation and abduction) were significantly lower in injured athletes compared with noninjured athletes ($P = .003$ and $P < .001$, respectively). Separate logistic regression models indicated that impaired hip strength increased future injury risk (external rotation: odds ratio [OR] = 1.23 [95% CI, 1.08-1.39], $P = .001$; abduction: OR = 1.12 [95% CI, 1.05-1.20], $P = .001$). Clinical cutoffs to define high risk were established as external rotation strength ≤20.3% BW (percentage of body weight) or abduction strength ≤35.4% BW.

Conclusion: Measures of preseason isometric hip abduction and external rotation strength independently predicted future noncontact ACL injury status in competitive athletes. The study data suggest that screening procedures to assess ACL injury risk should include an assessment of isometric hip abduction and/or external rotation strength.

Keywords: anterior cruciate ligament (ACL) injury; noncontact; prospective study; knee injury prevention; hip abduction strength; hip external rotation strength

The anterior cruciate ligament (ACL) is the most frequently ruptured ligament of the knee joint. According to a 2012 review article on the incidence rates of ACL injuries, the annual injury rate for competitive athletes is as high as 3.67%.[18] The highest number of ACL injuries is sustained among athletes who are involved in high-velocity or multidirectional sports such as basketball, soccer, and football. Within a given sport, female athletes have a higher incidence rate of ACL injuries than do male athletes.[18]

Approximately 70% of ACL injuries occur as a result of noncontact mechanisms, such as landing from a jump, forceful deceleration, cutting, or pivoting over a planted foot.[4,11,16] The term *noncontact* has not been consistently defined among researchers and thus may or may not include events in which an ACL injury is sustained from a physical perturbation during or before the injury

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The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546515616237

(indirect contact). Nonetheless, classic noncontact injuries are sustained without extrinsic contact to the knee (from an outside player or object) and are thought to result from the athlete's inherent movement patterns.[15] This means that noncontact ACL injuries are theoretically preventable, and as a consequence, identification of modifiable risk factors is essential for the success of ACL injury prevention programs.

Over the past decade, 3 prospective studies have provided evidence that abnormal lower extremity movement patterns heighten the risk of ACL injury. The first, conducted by Hewett et al,[6] reported that valgus motion and valgus moments during landing tasks predicted ACL injury in female athletes. Specifically, knee valgus moments predicted ACL injury status with 78% sensitivity and 73% specificity.[6] The second study, conducted by Zazulak et al,[27] determined that trunk control was predictive of ACL injury risk in athletes with no prior knee injury. Specifically, trunk displacement (lateral, flexion, and extension) predicted ACL injury risk with 83% sensitivity and 76% specificity.[27] In the third study, Paterno et al[19] reported that the uninvolved limb hip rotation moment predicted a second ACL injury (ipsilateral or contralateral) with 77% sensitivity and 81% specificity.[19] Collectively, these studies suggest that abnormal movement patterns at the trunk, hip, and knee are associated with an increased incidence of ACL injury.

Cross-sectional studies indicate that abnormal movements at the trunk, hip, or knee may be influenced, in part, by diminished hip strength. Several investigators have reported that decreased hip muscle strength is associated with greater knee valgus angles,[3,7,9,26] knee valgus moments,[12] and loss of frontal plane postural stability.[13] However, this has not been a universal finding among studies, as 3 previous investigations found no such relationship between frontal plane knee motion and hip strength.[17,22,23] These conflicting findings may be explained by differences in the tasks studied among investigators. Researchers reporting no relationship between biomechanical impairments and hip strength studied double-limb movements (ie, drop jump or lunge),[17,22,23] as opposed to single-leg tasks (ie, single-leg squat, step-down, single-leg jump, or single-leg stand) in which notable relationships were found.[3,7,9,12,13,26] Regardless, the effect of reduced hip muscle strength on ACL injury remains a concern because athletes involved in high-risk sports typically perform a combination of single-leg and double-leg activities.

To the best of our knowledge, no prospective studies have related hip strength to noncontact ACL injury risk in an athletic population. Given that deficits in hip muscle performance are thought to negatively affect movement patterns at the trunk, hip, and/or knee, it stands to reason that diminished hip strength may also predict future noncontact ACL injury. Although there are likely multiple factors that contribute to increased risk of noncontact ACL injury, hip strength is a modifiable risk factor that can be assessed easily in the clinical setting. As such, the primary aim of the present study was to determine whether reduced baseline hip strength (hip external rotation and hip abduction) predisposes athletes to future noncontact ACL injuries. We also sought to determine the clinical cutoffs for baseline hip strength (to distinguish between a high-risk and low-risk outcome) that would be able to predict future injury with high sensitivity and specificity.

METHODS

Subjects

Approximately 600 athletes from Ifsahan competitive clubs (futsal, soccer, volleyball, basketball, handball) that were most prevalent in the area were invited to participate in this study. Athletes who had sustained any lower extremity injury over the past 6 months or had any history of knee surgery were excluded from participation. Of the athletes initially contacted, 501 athletes consented to participate (138 females and 363 males). This study was approved by the institutional review board at the University of Isfahan.

Injury Surveillance

Athletes were followed over the course of a single season that occurred between June 2011 and July 2012. An ACL injury was defined as *noncontact* if it was sustained without direct blow (or contact) to the lower extremity. Indirect contact injuries (ie, resulting from upper extremity or trunk contact) were defined as noncontact. All other ACL injuries were labeled as *contact*. Magnetic resonance imaging or surgery was used to confirm all ACL injuries, and patient recall (ie, interviewing) was used to determine the injury mechanism (ie, noncontact vs contact). Patient recall was conducted at the end of the sport season, which was typically less than 6 months.

Hip Strength Assessment

Before the start of the sport season, bilateral isometric hip strength (abduction and external rotation) was assessed by use of a handheld dynamometer (Commander Power Track II; JTECH Medical Industries). For the isometric hip abduction assessment, athletes were side-lying on a treatment table, and a strap (positioned proximal to the iliac crest and secured around the table) was used to stabilize the pelvis. The hip was abducted 30°, and the dynamometer pad was placed 10 cm proximal to the lateral femoral epicondyle. Subjects then abducted their hip with maximum effort into the dynamometer pad for 5 seconds against manual resistance.[8,10] Three repetitions were performed, and the average value was used for analysis.

For the isometric hip external rotation assessment, athletes sat at the edge of a treatment table, and a strap (wrapped around the thigh) was used to stabilize the tested limb. The knee was flexed to 90°. Subjects then externally rotated their hip with maximum effort into the dynamometer pad (placed just proximal to the medial malleolus) for 5 seconds against manual resistance.[8,10] Three repetitions were performed, and the average value was used for analysis. All strength measures were recorded in kilograms and expressed as a percentage of body weight (% BW).

In total, 17 individuals were recruited to obtain the hip strength measures. Each tester completed a training session and reliability testing, which consisted of testing 5 subjects on 2 separate occasions. Intra- and interrater reliability (intraclass correlation coefficient; ICC) was calculated by use of an ICC(3,3) absolute agreement model. The 10 raters with the highest intrarater reliability (ie, average ICC of both hip measures) were used to obtain the hip strength measurements for the study participants. The intrarater reliability for the 10 raters selected to assess preseason hip strength was excellent. Average ICC values ranged from 0.95 to 0.99 for hip abduction strength and from 0.81 to 0.98 for hip external rotation strength. The interrater reliability was moderate to excellent (ICCs for hip abduction strength and hip external rotation strength were 0.71 and 0.99, respectively).

For hip strength, bilateral measures were obtained preseason. For injured athletes, the hip strength of the injured limb was used for analysis. For the noninjured athletes, the reported limb was selected so that the dominant to nondominant limb ratio was equivalent to that observed in the injured group (ie, 1:1 for females and 7:2 for males). This procedure was performed separately for each sex and minimized the potential influence of limb dominance as a confounder.[25] In the female cohort, for example, there were 6 noncontact ACL injuries. Specifically, 3 injuries were sustained on the dominant limb and 3 injuries were sustained on the nondominant limb. This equated to a 1:1 ratio. As such, in the noninjured group, we maintained the same ratio by randomly selecting equal dominant and nondominant limbs for analysis.

Statistical Analysis

Baseline data of subjects stratified by postseason injury status were initially compared by 2-way analysis of variance (ANOVA) and Fisher exact tests for continuous and categorical variables, respectively. Five separate 2-way ANOVAs were performed to determine the presence of main group effects (sex and injury status) and their potential interaction for each of the following dependent variables: age, height, weight, hip abduction strength, and hip external rotation strength. Two separate Fisher exact tests were performed to determine the association between injury status and sex and the association between injury status and sport.

Multivariate logistic regression was used to determine the risk factors that predicted future noncontact ACL injury. Potential baseline measures (age, height, weight, sport, sex, hip abduction strength, and hip external rotation strength) were selected as input variables based on the statistical results from the baseline subject data. Only variables that significantly affected injury status were selected. This included the variables from the 2-way ANOVAs that produced a significant main effect for injury (not sex) and any variables from the Fisher exact test that displayed a significant association with injury status. Checks for potential multicollinearity were subsequently performed (by use of Pearson correlation coefficient or chi-square [or Fisher] test as appropriate) to ensure that highly correlated variables were not included in the same model. The variables remaining were then used in a logistic model that predicted a binary outcome (injured vs noninjured).

TABLE 1
Baseline Characteristics of Athletes (N = 468) Stratified by Sex[a]

Characteristic	Males (n = 333)	Females (n = 135)
Age, y	21.5 ± 5.5	20.9 ± 4.2
Height, m	1.81 ± 0.10[b]	1.72 ± 0.08
Weight, kg	74.0 ± 13.7[b]	62.3 ± 10.1
Hip external rotation strength, % BW	24.0 ± 5.3[b]	17.0 ± 3.9
Hip abduction strength, % BW	40.1 ± 6.3[b]	31.4 ± 7.2

[a]Values are expressed as mean ± SD. % BW, percentage of body weight.

[b]Males demonstrated significantly higher values compared with females based on 2-way analysis of variance (all $P < .01$).

Receiver operating characteristic (ROC) curves were constructed independently for hip abduction and hip external rotation strength to determine (1) the overall discriminative accuracy of each for predicting noncontact ACL injury and (2) the optimal clinical cutoff value of each for distinguishing between a positive test (high risk) and negative test (low risk).[1] The overall accuracy of each strength test was assessed by evaluating the area under the curve (AUC), which ranged from 0 to 1 (with 0.5 equating to no better than chance alone and 1 inferring perfect accuracy). The optimal clinical cutoff point for each hip strength measure was selected by extrapolating the value on the ROC curve that maximized the sum of sensitivity and specificity. The corresponding sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, positive posttest probability, and negative posttest probability were reported. For most analyses, SPSS (v 22.0; IBM Corp) was used. MedCalc (v13.1.2; MedCalc Software) was used to calculate 95% confidence intervals for the sensitivity, specificity, positive likelihood ratio, and negative likelihood ratio. Two-tailed P values $<.05$ were deemed statistically significant.

RESULTS

Of the 501 athletes originally enrolled in the study, 25 males were removed from the final analyses due to inconclusive diagnosis related to injury. An additional 8 athletes (3 females and 5 males) were eliminated because they sustained a contact ACL injury (see below). Baseline descriptive data are provided for the remaining 468 athletes (135 females and 333 males) in Tables 1 and 2.

Injury Incidence

A total of 23 ACL injuries (9 in females, 14 in males) were sustained over the course of the season. For the male athletes, 9 (64%) of the ACL injuries that occurred were noncontact and the remaining 5 (36%) were contact. For the female athletes, 6 (67%) of the ACL injuries that occurred

TABLE 2
Baseline Characteristics of Athletes (N = 468) Stratified by Postinjury Status[a]

Characteristic	Injured (n = 15)	Noninjured (n = 453)
Age, y	21.8 ± 4.2	21.3 ± 5.2
Height, m	1.76 ± 0.09	1.78 ± 0.10
Weight, kg	69.5 ± 13.5	70.6 ± 13.7
Hip strength, % BW[b]		
External rotation	17.2 ± 2.9	22.1 ± 5.8
Abduction	30.8 ± 8.4	37.8 ± 7.6
Sport[c]		
Futsal	5 (6.9)	67 (93.1)
Soccer	3 (1.6)	179 (98.4)
Volleyball	1 (1.4)	70 (98.6)
Basketball	4 (5.0)	76 (95.0)
Handball	2 (3.2)	61 (96.8)
Sex[c]		
Male	9 (2.7)	324 (97.3)
Female	6 (4.4)	129 (95.6)

[a]Results are expressed as mean ± SD or n (%). % BW, percentage of body weight.

[b]Injury main effect was significant based on 2-way analysis of variance (all $P < .004$). Noninjured athletes demonstrated significantly higher values compared with injured athletes.

[c]Association with injury status was not significant based on Fisher exact test (all $P > .17$). Summation within each row totals 100%.

were noncontact and the remaining 3 (33%) were contact. The overall annual incidence of noncontact ACL injuries was 3.0% (15/501). The annual incidence of noncontact ACL injuries for male and female athletes was 2.5% (9/363) and 4.3% (6/138), respectively.

Subjects

All 2-way ANOVA interaction effects between sex and injury status for each of the dependent variables (age, height, weight, hip abduction strength, and hip external rotation strength) were nonsignificant ($P > .05$). However, there were significant main effects of sex for height, weight, hip external rotation strength, and hip abduction strength. When data were averaged across injury status, males were significantly taller ($P = .005$), heavier ($P = .009$), and stronger in the hip external rotators ($P < .001$) and hip abductors ($P < .001$) compared with females (Table 1). With regard to injury main effects, only hip external rotation strength and hip abduction strength were significant (Table 2). When data were collapsed across sex, noninjured athletes had significantly greater hip external rotation strength ($P = .003$) and hip abduction strength ($P < .001$) compared with injured athletes.

The Fisher exact test indicated that no significant association existed between sport and injury status ($P = .16$). Similarly, no significant results were observed for the association between sex and injury status ($P = .39$) (Table 2).

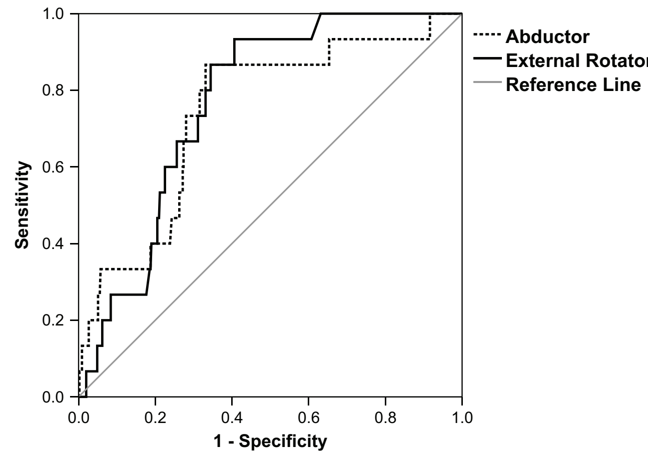

Figure 1. Receiver operator characteristic (ROC) curve used to calculate area under curve (AUC) and optimal clinical cutoff for each hip strength measure.

Regression Analysis

The predictor variables in the final logistic models included only hip strength measures because the other variables from the 2-way ANOVAs or Fisher exact tests did not influence injury status. Pearson correlation analysis indicated that hip external rotation and abduction strength were highly correlated ($r = 0.66$, $P < .01$). As such, we elected to build 2 separate models (1 model with hip abduction strength and 1 model with hip external rotation strength) to avoid multicollinearity. Our decision to create 2 separate models (as opposed to eliminating a strength measure) was based on our intent to evaluate the ability of each hip strength measure to predict noncontact ACL injury.

The final logistic regression results for each of the hip strength measures were similar (Table 3). Reduced hip external rotation strength was significantly associated with increased risk of noncontact ACL injury (odds ratio [OR] = 1.23 [95% CI, 1.08-1.39], $P = .001$), as was hip abduction strength (OR = 1.12 [95% CI, 1.05-1.20], $P = .001$). Stated alternatively, the odds of sustaining a noncontact ACL injury were increased for each 1-unit decrease in hip external rotation and hip abduction strength (expressed as % BW) by 23% and 12%, respectively. The models explained 11.2% and 10.2% of the variation in injury status (based on the Nagelkerke R^2) by use of hip external rotation and hip abduction strength predictors, respectively.

ROC Curve Analysis

ROC curve analysis (Figure 1 and Table 4) indicated that both hip external rotation strength and hip abduction strength tests (measured preseason) independently distinguished between athletes who later sustained an ACL injury and those who remained noninjured better than did chance alone (hip external rotation strength: AUC = 0.78 [95% CI, 0.70-0.86], $P < .001$; hip abduction strength:

TABLE 3
Final Logistic Regression Models for Predicting Noncontact Anterior Cruciate Ligament Injury in Athletes

Final Model	Predictor	Odds Ratio (95% CI)	*P* Value	Variation in Injury Status, % (based on Nagelkerke R^2)
Model 1	Hip external rotation strength	1.23 (1.08-1.39)	.001[a]	11.2
Model 2	Hip abduction strength	1.12 (1.05-1.20)	.001[a]	10.2

[a]Statistically significant at $P < .05$.

TABLE 4
Predictive Capacity of Baseline Hip Strength Tests for Predicting Noncontact ACL Injury in Athletes[a]

	Hip External Rotation	Hip Abduction
Cutoff, % BW[b]	20.3	35.4
AUC[c]	0.78 (0.70-0.86)	0.75 (0.63-0.88)
Sensitivity, %[d]	93 (68-99)	87 (60-98)
Specificity, %[e]	59 (54-64)	65 (60-69)
Positive likelihood ratio[f]	2.3 (1.9-2.7)	2.5 (2.0-3.1)
Negative likelihood ratio[g]	0.11 (0.02-0.75)	0.21 (0.06-0.75)
Positive posttest probability, %[h]	6.6	7.2
Negative posttest probability, %[i]	0.34	0.65

[a]Values in parentheses are 95% CIs. ACL, anterior cruciate ligament; AUC, area under the curve; % BW, percentage of body weight.

[b]Point on receiver operating characteristic (ROC) curve that maximized the sum of sensitivity and specificity. Athletes with a score less than or equal to the cutoff were classified as high risk (positive test). Athletes with score greater than the cutoff were classified as low risk (negative test).

[c]Ranges from 0 to 1. Values equal to 0.5 indicate that a test is no better at discriminating between injured vs noninjured athletes than chance alone. Values equal to 1 represent a test with perfect accuracy.

[d]Percentage of cases within the injured cohort correctly identified as sustaining a noncontact ACL injury using the cutoff.

[e]Percentage of cases within the noninjured cohort correctly identified as not sustaining a noncontact ACL injury using the cutoff.

[f]Sensitivity/(100 – Specificity). Ranges from 1 to infinity. Index of likelihood that injured athletes have a positive test (ie, less than or equal to the cutoff) compared with noninjured athletes. Larger values identify usefulness of the measure for predicting future injury (specifically noncontact).

[g](100 – Sensitivity)/Specificity. Ranges from 1 to 0. Index of likelihood that injured athletes have a negative test (ie, greater than the cutoff) compared with noninjured athletes. Smaller values identify the usefulness of the measure for predicting future noninjury (specifically noncontact).

[h]Probability an athlete sustains a noncontact ACL injury if baseline strength test is positive. Found by direct mathematical calculation: Posttest Odds = Pretest Odds × Positive Likelihood Ratio. Posttest odds are then converted to a probability. Pretest odds were 3/97 (which equates to a pretest probability of 3%, or the annual incidence rate of noncontact ACL injury in current study).

[i]Probability an athlete sustains a noncontact ACL injury if baseline strength test is negative. Found by direct mathematical calculation: Posttest Odds = Pretest Odds × Negative Likelihood Ratio. Posttest odds are then converted to a probability. Pretest odds were 3/97 (which equates to a pretest probability of 3%, or the annual incidence rate of noncontact ACL injury in current study).

AUC = 0.75 [95% CI, 0.63-0.88], *P* = .001). Given that the predictive capacity of each curve was adequate (ie, better than chance alone), optimal clinical cutoffs were subsequently established to identify athletes at high injury risk: hip external rotation strength ≤20.3% BW or hip abduction strength ≤35.4% BW (Table 4). For hip external rotation strength, a cutoff of 20.3% BW corresponded with a 93% sensitivity (95% CI, 68%-99%), 59% specificity (95% CI, 54%-64%), positive likelihood ratio of 2.3 (95% CI, 1.9-2.7), and negative likelihood ratio of 0.11 (95% CI, 0.02-0.75). For hip abduction strength, a cutoff of 35.4% BW corresponded with a sensitivity of 87% (95% CI, 60%-98%), specificity of 65% (95% CI, 60%-69%), positive likelihood ratio of 2.5 (95% CI, 1.9-3.1), and negative likelihood ratio of 0.21 (95% CI, 0.06-0.75).

DISCUSSION

The purpose of the present study was to prospectively determine whether baseline hip muscle strength predicted future noncontact ACL injury within an athletic population over the course of a single sport season. This study provides evidence that a significant relationship does exist between baseline hip strength and future noncontact ACL injury status. Specifically, increased hip strength had a protective effect against future injury (or diminished strength increased injury risk). Interestingly, our findings apply equally to male and female athletes.

Although it is well established that females have a higher incidence of ACL injuries than males,[18,21] we did not find such a relationship. The noncontact ACL injury incidence rate in our population was approximately 1.8 times higher for females than for males (4.3% vs 2.5%), but from a statistical standpoint, injury status was not affected by sex (Table 2). It should be noted, however, that female athletes have a higher rate than male athletes only when compared within the same sport. At the population level, males actually have a higher rate of ACL injury.[18,21] Therefore, it is possible that we did not find a sex difference in injury rates because we did not analyze athletes within the same sport and/or because our study lacked statistical power to establish such a difference.

In regard to hip strength, we built 2 separate univariate logistic models: model 1 using hip external rotation strength as a predictor of injury status and model 2 using hip abduction strength (Table 3). Considering that the correlation between the 2 strength measures was moderate to high ($r = 0.66, P < .01$), we anticipated that both measures would provide comparable predictive ability, and this was indeed the case. Examination of the 95% confidence intervals for the reported values (OR, AUC, sensitivity, specificity, positive likelihood ratio, and negative likelihood ratio) (Tables 3 and 4) shows that there was overlap for each, indicating that both hip strength measures had comparable ability for predicting noncontact ACL injury.

As noted above, the derived values for the positive likelihood ratio and negative likelihood ratio were used to calculate the probability of noncontact ACL injury given a positive (high risk) or negative (low risk) preseason hip strength test (Table 4). Athletes classified as high risk on their preseason hip abduction strength test had an increase in the probability of noncontact ACL injury from 3.0% to 7.2%. Athletes classified as low risk on their preseason hip abduction strength test had a decrease in the probability of noncontact ACL injury from 3.0% to 0.65%. Similar results were seen when we used the preseason hip external rotation strength test: Injury risk increased from 3.0% to 6.6% given a high-risk test but decreased from 3.0% to 0.34% given a low-risk test. The aforementioned values were derived by use of a preinjury risk of 3%, or the annual incidence rate of noncontact ACL injury in the current study.

Our study provides evidence that greater hip strength may protect against future noncontact ACL injury. This finding may seem counterintuitive, given that the ACL is anatomically part of the knee (not the hip), which is why prior prospective studies considering diminished strength as an ACL injury risk factor have focused on quadriceps and hamstring strength. In a 4-year prospective study, however, Uhorchak et al[24] reported that neither hamstring nor quadriceps strength (nor the corresponding hamstring to quadriceps ratio) was predictive of future noncontact ACL injury in athletes. As for the possible link between hip strength and ACL injury, a recent study by Baldon et al[2] demonstrated that increasing hip strength improved lower extremity kinematics thought to be associated with knee and patellofemoral joint injury (specifically decreasing ipsilateral trunk inclination, contralateral pelvic drop, and hip adduction excursions during a single-leg squat).

To the best of our knowledge, this is the first prospective study to establish a link between baseline hip strength and future noncontact ACL injury. However, this is not the first prospective study to demonstrate a relationship between diminished hip strength and postinjury status in athletes. Leetun et al[14] demonstrated prospectively that athletes who sustained an injury (ie, event that occurred during athletic participation and required medical attention) were significantly weaker in hip abduction and hip external rotation compared with their noninjured counterparts (as determined by use of handheld dynamometry). However, hip external rotation was the only significant predictor of injury risk over the course of a season based on logistic regression analysis. Leetun et al[14] did not specifically evaluate ACL injuries in their study.

The findings of the current study have several clinical implications. Most notably, we observed that an athlete's risk of sustaining an ACL noncontact injury was increased (on average) from 3% to 7% when either hip strength measure was less than or equal to the established cutoff that maximized the sum of sensitivity and specificity (20.3% BW for hip external rotation or 35.4% BW for hip abduction strength) (Table 4). Therefore, considering that diminished hip strength contributes to abnormal movement patterns at the trunk, hip, and knee[3,7,9,12,13,26] and that abnormal biomechanical patterns at the trunk, hip, and knee are independent risk factors for future noncontact ACL injuries,[6,19,27] our findings suggest that screening procedures to assess ACL injury risk should include an assessment of hip abduction and/or external rotation strength. However, our logistic models as a whole explained only 10% to 11% of the variation in injury status (Table 3), which suggests that increased risk of noncontact ACL injury likely is influenced by a multitude of factors, some nonmodifiable (eg, female sex, anatomic structure, and neuromuscular function) and others modifiable (eg, abnormal biomechanical movement patterns, environmental factors, strength, and fatigue).[5,18,20] As such, hip strength impairment is only one of several factors that clinicians need to be cognizant of when assessing an athlete's risk of noncontact ACL injury.

A number of limitations need to be considered in the evaluation of our results. First, we relied on patient interview at the end of the season to determine the ACL injury mechanism (ie, noncontact vs contact), making it difficult for us to ascertain that the correct mechanism was reported. Second, our results are based on hip strength measures acquired by use of a handheld dynamometer, rendering our clinical cutoffs inappropriate for other instruments. Third, the cause of noncontact ACL injuries is multifactorial and, unfortunately, it was not feasible for us to control for all potential variables. As a result, our reported values may overestimate (or even underestimate) the true effect of hip strength on injury risk. Fourth, we selected only a single clinical cutoff value for each hip strength measure. As such, our cutoff value only distinguished between low-risk and high-risk athletes (which could be labeled rudimentary, as we didn't include a moderate-risk group). Fifth, our exclusion criteria prevented the enrollment of athletes with any history of knee surgery (which included those at risk of sustaining a subsequent ACL injury after reconstructive surgery), suggesting that our findings may underestimate the effect of impaired hip strength on injury risk in athletes with prior knee injuries. However, our reporting of likelihood ratios does permit the calculation of posttest injury risk in other populations of interest (assuming the pretest probability of injury risk is known).

CONCLUSION

Our results indicate that baseline hip abduction and hip external rotation strength (measured by use of a handheld dynamometer) separately predicted future noncontact ACL injury status in competitive athletes. On average, the odds of sustaining a noncontact ACL injury were increased for each 1-unit decrease in hip external rotation and hip abduction strength (expressed as % BW) by 23% and 12%, respectively. Clinical cutoffs were established to identify athletes at high injury risk: hip external rotation strength $\leq$20.3% BW or hip abduction strength $\leq$35.4% BW. According to these strength cutoffs, athletes classified as low risk have an injury risk that decreases from 3% to less than 1%, while athletes classified as high risk have an injury risk that increases from 3% to 7%. Our findings suggest that clinical interventions and/or screening procedures should include evaluation of isometric hip strength, as reduced hip strength predisposes athletes to future noncontact ACL injury.

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