Systematic Review

Is There an Association Between Noncontact Anterior Cruciate Ligament Injuries and Decreased Hip Internal Rotation or Radiographic Femoroacetabular Impingement? A Systematic Review

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Purpose: To perform a systematic review to determine if there is (1) an association between decreased hip internal rotation and anterior cruciate ligament (ACL) tear rates; (2) an association between radiographic femoroacetabular impingement (FAI) and ACL tear rates; and (3) biomechanical evidence demonstrating increased strain in the ACL of patients with decreased hip internal rotation. **Methods:** A systematic review was performed using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Studies investigating relationships between hip motion, hip radiographs, and ACL tear were sought. Studies with Levels of evidence I-IV were eligible for inclusion. Study methodology/evidence were evaluated using Methodological Index for Non-Randomized Studies (MINORS), Strengthening the Reporting of Observational Studies in Epidemiology (STROBE), and Grading of Recommendations Assessment, Development, and Evaluation (GRADE) criteria. **Results:** Eleven studies were analyzed (2 cadaveric in vitro models, 8 clinical studies measuring hip internal rotation (2 concurrently assessing radiographic FAI), and 1 clinical study assessing radiographic FAI alone). Mean MINORS, STROBE, and GRADE for the studies was 82.4%, 20.9 out of 22, and "low," respectively. A total of 959 subjects (84.8% male; mean age 23.6 ± 3.8 years) were analyzed. Overall, 378 subjects sustained 427 ACL tears (399 primary ACL ruptures, 28 reruptures). Six of 8 clinical studies identified a significant association between limited rotation (internal rotation [IR; loss greater than 10°-20°], external rotation [ER], or combined IR + ER [loss greater than 20°]) and ACL tears. Two studies found an association between ACL ruptures and radiographic cam/pincer impingement. Two cadaveric models found a significant association between ACL strain and limited hip internal rotation. **Conclusions:** This systematic review identified a significant association between ACL tear and both limited hip rotation and radiographic FAI. **Level of Evidence:** Level IV, systematic review of Levels II-IV studies.

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Noncontact anterior cruciate ligament (ACL) injuries are common serious athletic knee injuries with an estimated annual incidence higher than 250,000.[1] Patients with ACL tears are frequently treated with reconstruction to stabilize the knee, improve function, return athletes to sport, and reduce the risk of meniscal and/or articular cartilage damage. Interest in ACL prevention programs has rapidly

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grown, especially focusing on modifiable biomechanical and neuromuscular factors.[2] An evolving evidence base for hip injuries secondary to abnormal pathomorphology (such as femoroacetabular impingement [FAI]) and/or lost rotational motion (with subsequent stress transfer up [proximal] or down [distal] the kinetic chain) has led authors to suspect a possible role for abnormal hip shape and/or motion in the multifactorial etiology of ACL tears.[3]

FAI may cause decreased hip motion secondary to femoral head asphericity (cam) or focal/global acetabular overcoverage (pincer). A restriction in hip rotational motion may be associated with increased risk of ACL injury by alteration of the kinematic and kinetic chains of the lower extremity that result in greater strain on the ACL, potentially increasing noncontact ACL injury risk. Recent investigations support this association.[4-14] The proposed mechanism is via a compensatory increase in tibial internal rotation, abduction, and anterior tibial translation in patients with limited hip range of motion (ROM).[5] This establishes restricted hip internal rotation as a potential factor that predisposes an individual to noncontact ACL injury.[3] However, conflicting evidence does exist as previous investigations have demonstrated that increased internal rotation at the hip was thought to cause a greater risk of ACL rupture.[15] The authors of the latter proposed that a larger available internal rotation motion at the hip, in concert with increased tibial external rotation, could result in a valgus knee movement and potentially increase the risk of ligament injury.

The purpose of this investigation was to perform a systematic review to determine (1) if an association exists between decreased hip internal rotation and ACL tear rates; (2) if an association exists between radiographic FAI and ACL tear rates; and (3) if there is biomechanical evidence that demonstrates increased strain in the ACLs of patients with decreased hip internal rotation. The study hypotheses were as follows: (1) decreased hip internal rotation would be associated with increased ACL tear rates; (2) radiographic FAI would be associated with increased ACL tear rates; and (3) decreased hip internal rotation would increase strain on the ACL in biomechanical studies.

Methods

Identification of Literature

A systematic review was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on April 4, 2016 (registration ID: CRD42016037304). Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed.[16] Separate electronic searches were conducted by 2 authors (N.B. and R.A.B.) using the following databases: PubMed, Cochrane Central Register of Controlled Trials, SPORTDiscus, and Scopus. The searches were performed on June 3, 2016, and updated on January 16, 2017. The search phrases used a combination of *anterior cruciate ligament*, *ACL*, *femoroacetabular impingement*, *FAI*, *hip impingement*, and *hip rotation* as subject headings for searches in the databases mentioned above. Clinical and basic science studies investigating relationships of hip motion, hip radiographs, and ACL tear were sought for inclusion.

Selection Criteria

Studies with levels of evidence I to IV written in English language were eligible for inclusion. Book chapters, abstracts, review articles, Level V evidence, and non-English articles were excluded. No limit on clinical investigation follow-up was placed on otherwise eligible studies. Different studies with the same population from the same institution (duplicate studies) were eligible for inclusion. However, only the study with the largest number of subjects, highest level of evidence, longest follow-up, or most relevant information to the topic of this systematic review was retained for analysis and the other(s) was (were) excluded. All titles from the search results were screened and inclusion/exclusion criteria were applied to select relevant articles (Fig 1).

Data Extraction and Analysis

Three authors (N.B., R.A.B., and D.A.D.) independently reviewed all remaining articles using a standardized methodology.[17] The data extracted from each article included study title, authors, journal, publication date, years of patient enrollment, conflict of interest reporting, study type and design, level of evidence, involvement of a single center versus multicenter, country of origin, primary/secondary purpose, hypothesis, inclusion/exclusion criteria, outcome measures, number of patients enrolled (as well as breakdown of ACL injured/control patients and male/female patients), number of hips analyzed, mean age, number of providers performing the study, blinding, results, and limitations. Data extracted on hip analysis within each article included presence of FAI (cam, pincer, or both), hip laterality (right/left), presence of labral tear, presence of arthritis, and radiographic parameters (including alpha angle, lateral center-edge angle, presence of ischial spine/posterior wall signs, and Tönnis grading).

Each reviewer computed an individual Methodological Index for Non-Randomized Studies (MINORS) score for each article.[18] This scoring system involves 8 components for noncomparative studies and 12 components for comparative studies. Each component is graded on a scale from 0 to 2 based on reporting and

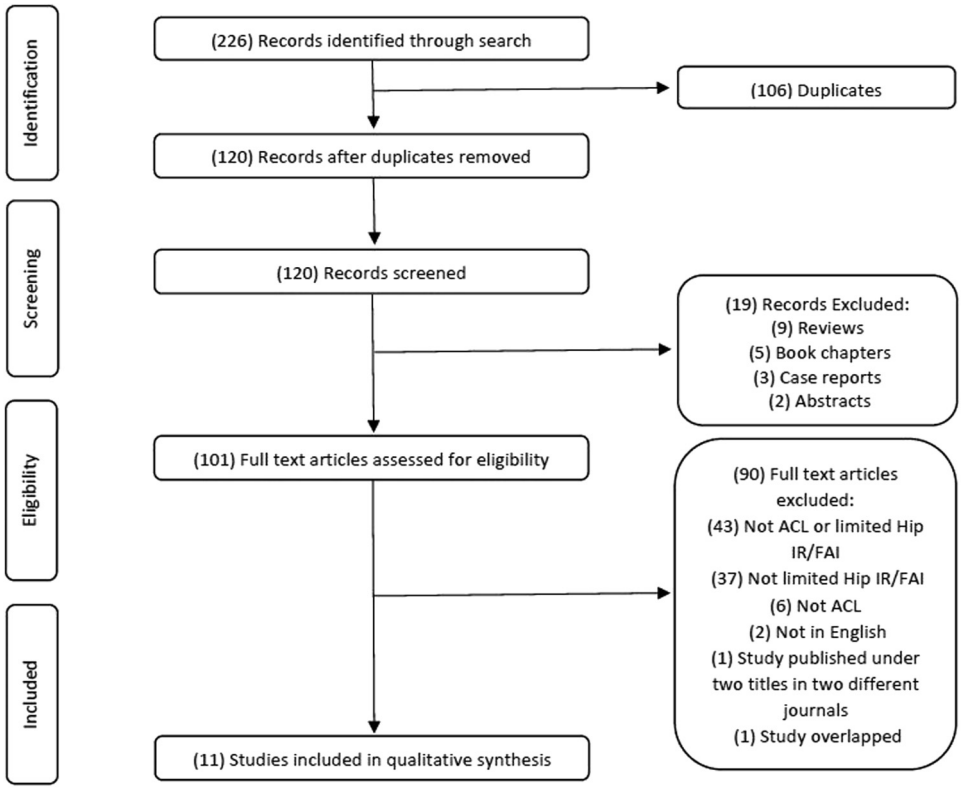

Fig 1. PRISMA flowchart summarizing the literature search, screening, and review.

adequacy of methodology for a potential total of 16 and 24 points for noncomparative and comparative studies, respectively. MINORS scores for each article were reported as both raw scores and percentages. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) and Grading of Recommendations Assessment, Development, and Evaluation (GRADE) criteria were also used because both systems were intended for use in observational studies. The checklist of items to be contained in an observational study taken from the STROBE statement aided in evaluating methodological quality.[19] The GRADE system was used to grade the quality of evidence in each article.[20] According to the GRADE criteria, all observational studies start out with a grade of low and can have points subtracted or added depending on limitations, consistency, directness, and strength of association of data within the article. This could potentially drop the final grade down to a score of very low or raise the grade to moderate or high. After the 3 different methodological scoring systems were employed, the overall quality of evidence for the studies included was to be judged by the authors on a spectrum of excellent, good, fair, and poor. Homogeneous Level I evidence data would be combined for meta-analysis, if possible. However, if meta-analysis was unable to be performed owing to dissimilar, heterogeneous, or low-quality (less than Level I) evidence, then a best-evidence synthesis would be performed.[21] Statistical significance, when applicable, was extracted from each individual study.

Results

Study Demographic Characteristics

Eleven articles were included in the final qualitative analysis (Table 1). Of these 11 articles, 2 were cadaveric in vitro models that assessed ACL strain and fatigue failure with limited hip motion.[5,6] The 9 remaining articles contained 959 total patients (84.8% male, 15.2% female; mean age 23.6 ± 3.8 years).[4,7-14] One study was a combined study that assessed hip internal rotation in a cohort of 34 patients and ACL strain in a 3D computer model with varying limitations in hip internal rotation. Four studies assessed hip internal rotation in 167 patients with primary ACL injuries. One study assessed hip motion in 28 patients with ACL reruptures. Two studies were combined studies that assessed hip ROM and hip radiographic findings in 105 patients with primary ACL rupture. One study assessed radiographic findings of impingement at the hip in 48 patients with primary ACL ruptures. There were 378 subjects with 427 ACL ruptures (399 primary ACL ruptures, 28 ACL reruptures). Methodological quality (Table 2) demonstrated a mean MINORS score of 11 of 16 for noncomparative studies and 20.7 of 24 for

Table 1. Articles Included in Final Review

Article, Year	Journal	Level of Evidence	Study Design	Patient Population/ Country of Origin	Outcome Measure	No. of Patients in Study Group/No. of ACL Injuries (No. of Hips)	No. of Patients in Control Group (No. of Hips)	Outcomes
Tainaka et al.,[13] 2014	*Knee*	3	Case- control	Male and female student athletes/ Japan	Hip ROM	44 patients/44 ACL injuries (88 hips)	123 patients (246 hips)	• Hip IR and ER were 35° (± 9.1°) and 45.7° (± 6.1°) in ACL injury group compared with 50.2° (± 7.2°) and 56.3° (± 6.8°) in control group ($P < .05$) • Decreased odds of ACL injury per 10° increase in hip IR ($P < .001$)
Gomes et al.,[8] 2008	*Arthroscopy*	3	Case- control	Male soccer players/ Brazil	Hip ROM	50 patients/50 ACL injuries (100 hips)	50 patients (100 hips)	• Mean hip IR was 26.4° (± 7.7°) in study group compared with 39° (± 7.1°) in controls ($P < .001$) • Patients with 70° and 80° total ROM (20° and 10° less than normal, respectively), OR of ACL injury were 7.87 (95% CI, 3.07-20.4) and 11 (95% CI, 3.95-30.3) respectively
Hertel et al.,[10] 2004	*J Sports Sci Med*	3	Case- control	Male and female college students/ U.S.A.	Hip ROM	20 patients/24 ACL injuries (40 hips)	20 patients (40 hips)	• Hip IR and ER were 39.14° (± 8.31°) and 31.41° (8.88°) in ACL injury group compared with 41.2° (± 9.13°) and 30.51° (± 8.98°) in control group (no significant difference)
Bedi et al.,[7] 2016	*Knee Surg Sports Traumatol Arthrosc*	4	Cohort	2012 NFL Combine/ U.S.A.	Hip ROM	324 patients/34 ACL injuries (648 hips)	-	• Decrease in IR of left hip was associated with increased odds of ACL injury in the ipsilateral knee ($P = .0001$) and contralateral knee ($P < .0001$) • Decrease in IR of right hip trended toward increased odds of ACL injury (not significant)
		—	3D computer model	Cadaver/U.S.A.	ACL Strain	taken from MRI scan of single male cadaveric lower limb		• Predicted increased peak AM bundle ACL strain as hip IR range is decreased (strain for 5° of hip IR was 22.5% greater than for 10° of hip IR)
Amraee et al.,[4] 2017	*Knee Surg Sports Traumatol Arthrosc*	4	Cohort	Male athletes/Iran	Hip ROM	53 patients/53 ACL injuries (53 hips)	—	• Increase in hip IR by 1° shows a decrease in probability of ACL injury ($P = .003$)
Gomes et al.,[9] 2014	*Knee Surg Sports Traumatol Arthrosc*	4	Case- control	Male soccer players/ Brazil	Hip ROM	28 patients/69 ACL injuries (56 hips)	27 patients (54 hips)	• Mean combined hip IR and ER among patients with ACL rerupture was 44.8° (± 8.7°) compared with 56.2° (± 10.3°) in healthy controls (no significant difference)
Lopes Jr. et al.,[11] 2015	*Knee Surg Sports Traumatol Arthrosc*	3	Case- control	Male soccer players/ Brazil	Hip ROM	45 patients/45 noncontact ACL injuries (45 hips)	35 patients/35 contact ACL injuries (35 hips)	• Hip IR/ER of noncontact and contact ACL-injured groups were 28.6° (± 5.7°)/37.5° (± 4.3°) and 35.6° (± 5.7°)/43.7° (± 6.6°) respectively ($P < .001$) • Noncontact ACL ruptures more likely to have combined hip IR + ER <80° and <70°, PR 8.57 (95% CI, 2.77-26.5) and PR 3.73 (95% CI, 2.12-6.57) respectively
					Hip radiographic findings	(45 hips)	(35 hips)	• No difference in hip radiographic findings

(continued)

Table 1. Continued

Article, Year	Journal	Level of Evidence	Study Design	Patient Population/ Country of Origin	Outcome Measure	No. of Patients in Study Group/No. of ACL Injuries (No. of Hips)	No. of Patients in Control Group (No. of Hips)	Outcomes
VandenBerg et al.,[14] 2016	*Arthroscopy*	2	Case- control	Male and female patients/U.S.A.	Hip ROM	25 patients/25 ACL injuries (50 hips)	25 patients (50 hips)	• Mean hip IR and combined IR + ER were 23.4° (± 7.6°) and 60.3° (± 12.4°) in the study group compared with 30.4° (± 10.4°) and 72.6° (± 17.2°) in the control group ($P < .01$) • Decreased odds of ACL injury per 10° increase in hip IR ($P = .015$)
					Hip radiographic findings	(25 hips)	(25 hips)	• Greater incidence in posterior wall sign ($P = .004$) and ischial spine sign ($P = .042$) in study group compared with controls
Philippon et al.,[12] 2012	*Knee Surg Sports Traumatol Arthrosc*	3	Case-control	Male and female patients/U.S.A.	Alpha angle on hip radiograph	48 patients/48 ACL injuries (96 hips)	42 patients/42 non-ACL knee injuries (84 hips)	• Hip alpha angles on ipsilateral and contralateral limbs of ACL-injured patients were 84° (± 13°) and 77° (± 17°) compared with 59° (± 7°) and 60° (± 9°) in non-ACL-injured patients ($P < .01$) • Patients with alpha angles greater than 60° were 27 times more likely to be in the ACL injured group ($P = .001$)
Beaulieu et al.,[5] 2014	*Am J Sports Med*	—	In vitro model	Cadavers/U.S.A.	ACL strain	20 knee specimens (all tested with and without limited femoral rotation)		• Peak AM bundle ACL strain was 28.4% larger when femoral rotation was locked compared with when it was free • Inverse relationship between ACL strain and internal femoral rotation during the simulated single leg pivot landings ($P < .001$) • 45% greater peak ACL strain in female specimens compared with male ($P = .03$)
Beaulieu et al.,[6] 2015	*Am J Sports Med*	—	In vitro model	Cadavers/U.S.A.	ACL fatigue failure	32 knee specimens (16 limited femoral rotation, 16 without)		• Limited range of internal femoral rotation increased the risk of ACL failure by 8.3 times ($P = .048$) when compared with free rotation • Sex, ACL femoral attachment angle, and tibial eminence volume did not significantly predict ACL failure

ACL, anterior cruciate ligament; CI, confidence interval; ER, external rotation; IR, internal rotation; PR, prevalence ratio; ROM, range of motion.

Table 2. Methodological Assessment and Quality of Evidence of Articles

Observational Studies	MINORS Noncomparative (Raw)	MINORS Comparative (Raw)	Overall MINORS (%)	STROBE	GRADE
Bedi et al.[7]	12/16	—	75	21/22	Low
Tainaka et al.[13]	—	21/24	87.5	22/22	Low
Hertel et al.[10]	—	18/24	75	20/22	Very low
Amraee et al.[4]	10/16	—	62.5	21/22	Very low
Gomes et al.[8]	—	17/24	70.8	19/22	Low
Gomes et al.[9]	—	19/24	79.2	22/22	Low
Lopes Jr. et al.[11]	—	24/24	100	21/22	Moderate
VandenBerg et al.[14]	—	22/24	91.7	22/22	Moderate
Philippon et al.[12]	—	24/24	100	20/22	Moderate
Mean Scores:	11/16; 68.8%	20.7/24; 86.3%	82.4%	20.9/22	Low

NOTE. Overall Quality: Good.

comparative studies. Using the STROBE checklist for observational studies, there were 20.9 of 22 items reported. When using the GRADE system for grading quality of evidence, the average final grade of the studies was low. Given the scores from these 3 separate grading systems, the overall quality of the studies included was deemed good by the authors on a spectrum of excellent, good, fair, and poor.

Hip Motion and ACL Tear—Clinical

There were 8 studies that evaluated the association between hip motion and ACL ruptures.[4,7-11,13,14] Hip motion was measured with use of a goniometer in 1,605 hips of 869 patients (330 patients with 385 ACL injuries and 539 patients without ACL injury). Five of the 8 studies that measured hip rotational (internal and internal plus external sum) motion revealed statistically significant ($P < .05$) differences between hip motion of ACL-injured patients compared with non-ACL injured controls.[4,7,8,13,14] One study (80 subjects) found significantly less hip internal rotation, external rotation, and abduction in noncontact ACL-injured patients compared with patients with contact ACL injuries.[11] The 2 remaining hip motion studies (95 subjects) did not show a significant association between hip motion and ACL tears (1 study assessed primary ACL injured patients[10]; 1 study assessed patients with ACL rerupture after reconstruction[7]). Overall, a loss of more than 10° to 20° of internal rotation significantly increased the risk of noncontact ACL tear. Overall, a loss of more than 20° of total rotational motion (internal and external rotation sum) significantly increased the risk of noncontact ACL tear.

Radiographic FAI and ACL Tear

Three studies assessed 310 hips in 220 patients for the presence of FAI on hip radiographs. Two studies (140 subjects) found a significantly greater incidence of FAI on hip radiographs in ACL-injured patients versus controls.[12,14] Of these, one study found that patients with alpha angles greater than 60° were 27 times (95% CI, 6.4-131) more likely to be in the ACL-injured group ($P = .001$).[12] The other study found a greater incidence of pincer impingement as assessed by the presence of posterior wall ($P = .004$) and ischial spine signs ($P = .042$) on radiographs.[14] The third radiographic study (80 subjects) compared noncontact ACL-injured patients to contact ACL-injured patients and did not find a significant difference in the presence of cam- or pincer-type FAI between the 2 groups.[11]

Hip Motion and ACL Strain—In Vitro

The 3D computer model and both cadaveric in vitro biomechanical studies revealed significantly increased strain and fatigue failure on the ACL with limited femoral rotation.[5-7] The cadaveric studies revealed that peak AM bundle ACL strain was 28.4% larger when femoral rotation was locked compared with when it was free and that this limited rotation increased the risk of ACL failure by 8.3 times.[5,6] Female specimens showed significantly greater peak ACL strain, but sex did not significantly predict ACL failure.

Discussion

This systematic review has shown that both decreased hip internal rotation and radiographic FAI are associated with increased ACL tear rates, confirming the first 2 study hypotheses. Additionally, biomechanical evidence demonstrated that limited femoral rotation increased ACL strain and risk of failure, confirming the third study hypothesis. Although these associations were demonstrated, this does not imply FAI or decreased hip internal rotation caused the ACL tear. The hypothesis to be tested further includes the likely mechanism that decreased hip internal rotation results in increased tibial internal rotation, abduction at knee (valgus), and anterior tibial translation with resultant increased strain on the ACL. Future research should focus on investigation of this relationship to determine if a causal relationship exists and to determine if actions taken to improve hip ROM, both surgical (correction of FAI) and nonsurgical (physical therapy), also act to decrease the risk of ACL injury.

The association between limited hip ROM and ACL tears is conceivable when the knee's role in mobility is thought of in concert with the lower extremity and overall kinematic and kinetic chain in its entirety. Limited hip internal rotation may transfer stress above (sacroiliac joint, spine, upper extremities) or below (knee, foot/ankle) the hip.[3,22] As many patients with radiographic "abnormalities" such as cam or pincer morphologies may be completely asymptomatic,[23] this condition may go unnoticed by the patient, with the exception of an occasional limitation of athletic motion (but unreported).[8] Patients in one study with ACL reruptures[9] had mean hip total rotational motion (sum of internal and external rotation) measurements nearly 40° lower than healthy patients in other studies[8] and nearly 20° lower than patients who sustained only a single ACL injury,[8] indicating that loss of hip rotation (both internal and external) is possibly due to a "time-dependent reduction" in motion. This could be related to time spent playing a particular sport. Another possible explanation for this association is that decreased hip internal rotation could be a result of an ACL injury as opposed to the other way around.[8,9]

Increased ACL tear rates are associated with radiographic findings of FAI for the same reasons they are associated with limited hip internal rotation. Deficits in hip flexion and rotational motion are known clinical examination findings of FAI and may result in part from the soft tissue imbalance (musculotendinous imbalance such as iliopsoas, adductor complex, and hamstring, among others, or capsular adaptations) caused by impingement or from the bony impingement itself.[12] The radiographic studies presented in this review sought to correlate ACL ruptures with radiographically diagnosed FAI, with or without the presence of clinical examination findings of impingement.

Increased ACL strain and fatigue failure during pivot landings in the biomechanical studies were theorized to associate with limitations in femoral rotation for several reasons.[5] First, the decreased femoral rotation led to an increase in peak deceleration of tibial internal rotation. This caused a mismatch in the coordinated rotation of the femur and tibia leading to increased ligamentous strain. Also, the increased tibial internal deceleration appeared to be coupled with anterior translation of the tibia that further stressed the ACL. Repetitive cycles could lead to ACL fatigue failure due to accrued microdamage and the ligament's inability to remodel both in vivo and as presented in the cadaveric models.[6] The differences noted in ACL strain with regard to sex were postulated to arise from the smaller cross-sectional area of the cruciate ligaments in female specimens that were placed under the same testing conditions as male specimens with larger ligaments.[5]

Limitations

The limitations of this review stem from each of the studies included. For the biomechanical studies, knee specimens were taken from middle-aged cadavers as opposed to younger specimens. The controls were matched pairs that lead to the assumption that available hip internal rotation was the only variable that affected ACL strain in the experiment and that this same trend would occur in specimens of any age. However, the methods of handling specimens prior to each experiment (such as the degree to which a frozen specimen is thawed and the resultant elasticity of the tissue) introduce other potential confounding variables. Five of the 9 nonbiomechanical studies contained Level III evidence, and of the remaining 4 studies, 1 contained Level II evidence and 3 had Level IV evidence. Some of the studies that measured hip ROM found statistically significant differences that may or may not have been clinically significant differences in hip ROM. Not to mention, several of the studies that found no significant difference may not have been powered to detect such a difference between the groups presented.[7,9,10] Further, a minimal clinically important difference or minimal detectable change is not currently available for measurement of differences in hip range of motion. What a statistical test detects as a statistically significant difference may not equate to a clinically relevant difference, a difference that the patient is able to perceive. This is a relevant and necessary area of future investigation. Also, goniometer measurements are not free of error but use of a goniometer generally overestimates ROM measurements.[24] The studies from Brazil only included soccer players, and the trends found within this population of athletes may not translate to athletes in other sports.[8,9,11] Nonetheless, the study of Tainaka et al. demonstrated a similar trend in basketball players, which indicates that this association may be seen in other athletic populations. Strengths of this review include the sample size and overall good quality of articles included. The methodological quality of the studies included in this review in terms of their mean MINORS score was 82.4%.[18] The STROBE checklist was also used to gauge the methodology of each study. Collectively, the studies demonstrated around 95% compliance with the STROBE criteria for observational studies. The average grade for quality of evidence was low based on the GRADE grading system, and this is to be expected because observational studies, as mentioned before, start with a default score of low.

Conclusions

This systematic review identified a significant association between ACL tear and both limited hip rotation and radiographic FAI. The significant associations found in this review may be helpful in reducing the risk of

injury. Future research should focus on investigating if a causal relationship exists between FAI and ACL tears.

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