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Association between lower extremity muscle strength and non-contact ACL injuries

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Abstract

Purpose: To prospectively investigate the association between isolated and functional lower extremity muscle strength, and the risk for non-contact ACL injury in Norwegian female elite handball and football players.

Methods: From 2007 through 2015, premier league players participated in strength testing and were prospectively followed for ACL injury risk. At baseline, we recorded player demographics, playing and ACL injury history, and measured peak concentric isokinetic quadriceps and hamstrings torques (60º/s), HQ-ratio, isometric hip abduction strength and 1RM in a seated leg press. We followed a pre-defined statistical protocol where we generated 5 separate logistic regression models, one for each of the proposed strength risk factors and adjusted for confounding factors. New ACL injury was the outcome, using the leg as the unit of analysis.

Results: A total of 57 (6.6%) out of 867 players (age: 21±4 yrs; height: 170±6 cm; body mass: 66±8 kg) suffered from a non-contact ACL injury after baseline testing (1.8±1.8 yrs). The OR of sustaining a new injury among those with an ACL injury history was 3.1 (95% CI 1.6 to 6.1). None of the 5 strength variables selected were statistically associated with an increased risk of ACL rupture when adjusted for sport, dominant leg, ACL injury history, and height.

Conclusion: Peak lower extremity strength was not associated with an increased ACL injury risk among female elite handball and football players. Hence, peak strength, as measured in the present study, cannot be used to screen elite female athletes to predict injury risk.

Key words: Female; handball; football; anterior cruciate ligament; muscle strength; screening, injury risk

Introduction

Anterior cruciate ligament (ACL) injuries represent a serious concern in sports, not only because of time-loss from sport, but also the long-term health consequences: a substantially increased risk of knee osteoarthritis and impaired lower limb function (26). Typically, ACL injuries occur in pivoting sports with rapid direction changes and frequent single-leg landings, often with the athlete out of balance and almost always without direct contact to the knee (13,27). Females participating in sports such as football, basketball, floorball, and handball have a 3-5 times higher ACL injury risk than their male counterparts (29,37).

Although the etiology for ACL injuries is not fully understood, ACL injuries are likely multifactorial in nature, possibly related to a combination of neuromuscular, biomechanical, anatomical, and hormonal factors (30). Though associations between knee kinematics and future ACL injury risk are weak (14), motion patterns are suggested to play a crucial role in the injury causation (10,13,27). Effective ACL injury prevention programs focus on teaching frontal plane knee control and proper knee alignment during static and dynamic tasks (18,24,28,36).

The role of lower extremity strength, as modifiable risk factor to counterbalance poor knee joint stability and motion patterns, is widely discussed. Muscle strength, recruitment and co-activation of hamstrings and quadriceps muscles may be critical to successfully stabilize the joint and protect the ACL from rupture (4,17). Following a hamstring exercise protocol to fatigue, the estimated ACL load during side-step cutting increased by 36% in recreationally active females (38). Thus, it may be hypothesized that deficits in hamstring strength contribute to an increased ACL injury risk in female athletes.

In a case-control study, hamstrings strength and hamstrings-to-quadriceps (HQ) strength ratio was lower among 22 female athletes who went on to suffer an ACL injury compared to 88 matched controls (23), implying that a decreased HQ-ratio may represent a risk factor for a future ACL injury. However, in a 4-year prospective study following 859 military academy cadets there was no effect of concentric or eccentric quadriceps or hamstrings strength when comparing the 16 male and 8 female cadets who suffered an ACL injury to those without injury, irrespective of gender (33). In other words, the literature in this field is limited, and the results conflicting.

Hip strength is ascribed a significant role in the control of frontal plane knee motion (7). Weakness in the hip abductor muscles may predispose an athlete to greater hip adduction and hip internal rotation, thereby increasing medial knee motion and knee abduction moments, possibly increasing ACL injury risk (11,31). It follows that greater hip abduction strength should reduce ACL load. To date, there are no prospective cohort studies addressing hip strength as a potential risk factor for ACL injury.

In addition to reduced peak knee extension and flexion measures, low functional lower extremity strength, defined as the combined strength of the gluteal, quadriceps and hamstrings muscles, is hypothesized to increase injury risk. However, as with hip abduction strength, no data are available to link functional strength to prospective ACL injury risk.

To successfully tailor and implement injury prevention programs, it is of utmost importance to identify modifiable risk factors. Many effective multicomponent lower limb injury prevention programs include exercises focusing on lower extremity strength and core stability (15), and are also fundamental components of conditioning programs at the elite level (19). As compliance with injury prevention training remains a challenge in real life for various reasons, as e.g. being considered as time consuming or not sport-specific (20), establishing a positive link between improved strength and reduced ACL injury risk would strengthen the rationale behind such programs.

Thus, the purpose of this prospective cohort study was to assess whether reduced peak isokinetic, isometric, or functional lower extremity strength were associated with an increased risk for ACL injuries in female elite handball and football players.

Methods

Study design and participants

This investigation represents a secondary analysis of a cohort study designed to examine risk factors for noncontact ACL injuries in female elite handball and football players (14). The a priori hypothesis was to assess whether motion patterns, specifically dynamic knee valgus, during landing and side-step cuttings are associated with ACL injury risk. We also measured a range of other neuromuscular, anatomic, genetic, and biomechanical variables, but these analyses should be considered explorative to better understand the multifactorial etiology of ACL injuries.

Data were collected over an 8-year period (2007-2015). Players with a first-team contract who were expected to play in the premier league during the 2007 season were eligible for participation. From 2008 through 2014, new teams advancing to the premier league and new players from included teams were invited for pre-season tests. From 2009, we also included football players from the female premier league. We have baseline screening data of 429 handball and 451 football players. To examine the reproducibility of the strength tests, we also assessed a total of 144 players twice with 1 to 5 yrs between tests.

Following the start of screening tests in 2007, we recorded all complete ACL injuries through May 2015. For any ACL injury occurring during regular team training or competition, we contacted the injured player by phone to obtain detailed medical data and a description of the injury situation. The injury mechanisms were self-reported as contact (i.e. direct contact to the lower extremity), indirect contact (i.e. contact with other body parts) or non-contact, and injuries were categorized into two groups; non-contact/indirect contact or contact (27). All ACL injuries were verified by MRI and/or arthroscopy.

Risk factor screening tests

We used a comprehensive test battery to assess potential demographic, neuromuscular, biomechanical, anatomical, and genetic risk factors for an ACL injury. The screening tests were conducted at the Norwegian School of Sport Sciences in the pre-season, June through August for handball and February through March for football. Each player spent about 7 h in total to complete the screening, which also included information, warm-up trials at all test stations, as well as a lunch break. We asked all players to complete a questionnaire to collect data on demographics, elite playing experience and history of any previous injuries to the ACL. Data from 4 strength tests were included in the current study. Before each of the strength test stations, the players warmed up for 5 min on a cycle ergometer with moderate load (70-100 W).

Quadriceps and hamstrings strength

Maximal isokinetic knee extension and flexion torque were tested in a Technogym REV 9000 dynamometer (Gamboletta, Cesena, Italy). We used a standardized test protocol with gradually increasing intensity and recorded the peak torque (Nm) for concentric quadriceps and hamstring contraction on both legs. The axis of rotation of the dynamometer was individually aligned with the knee joint, and the hip angle was 90º. We used straps to minimize movements of the torso and the thigh segment of the tested extremity. The player held her arms across the chest. The test range of motion was 90° through 15° of knee flexion, with an angular velocity of 60°/s. Consequently, HQ-ratio was calculated for concentric strength at 60°/s.

After the testing in February 2012, the dynamometer was replaced by a new isokinetic dynamometer (Humac Norm, CSMi, Stoughton, MA, USA), and a similar proportion of handball (20%) and football players (22%) was tested with the new isokinetic dynamometer. Test-retest reliability of 27 recreational athletes from a separate cohort revealed excellent reproducibility with ICC-values (3,k) of 0.93 to 0.96 between the two dynamometers. However, mean peak muscle torque was on average 10 to 12% higher on the new dynamometer.

Hip abduction strength

We measured maximal isometric hip abduction strength with a handheld dynamometer (Hydraulic Push-Pull Dynamometer, Baseline® Evaluation instruments, White Plains, NY, USA through 2011; MicroFET, Hoggan Health Industries, Salt Lake City, Utah, USA from 2012) with the player in a supine position on an examination table. The pelvis, across spina iliaca anterior superior, and contralateral thigh were fixed with straps to the table. The player held her arms across the chest to avoid support from the arms or torso, while contracting her hip abductors. Isometric abduction strength was measured with the leg in extended and neutral position. We placed the dynamometer 3-5 cm proximal to the lateral malleolus and applied resistance in a fixed position for at least 2 s until a maximal contraction had been reached. The player was allowed one test trial followed by 2 trials, of which the best, measured in kg, was recorded for analysis.

Functional lower extremity strength

To assess the combined maximal strength of the gluteal, quadriceps and hamstrings muscles, we used a custom-made plate-loaded, seated leg press machine. The measurements proved to have excellent reliability, even with different testers involved (ICC=0.83, unpublished data). The feet were placed approximately shoulder width apart and the players lowered the weights until 100° of knee flexion was achieved, before pushing back to the starting position of extended legs (25). We measured the footplate position at 100° of knee flexion during warm up and provided visual feedback of the proper depth throughout the remaining lifts. Based on a standardized test protocol with gradually increasing load, we recorded one repetition maximum (1 RM, kg). For the 2008 handball sub-cohort (6% of all players), all leg press strength measures are missing due to test procedural errors.

Ethics approval

The Regional Committee for Medical Research Ethics; South-Eastern Norway Regional Health Authority, and by the Norwegian Social Science Data Services, Norway approved the study. Players signed a written informed consent form before inclusion, including parental consent for players aged <18 yrs.

Statistical protocol

Data were analysed using STATA, version 12 (StataCorp, College station, Texas, USA), and descriptive data are presented as means with standard deviations (SD) and frequencies with corresponding percentages. The dominant leg was defined as the preferred kicking leg.

Muscle strength measures are presented as absolute and body mass normalized values. We did not impute individual missing strength values, as the average proportion of missing data did not exceed 6%. Only legs with missing data in all 4 strength tests were excluded from the final analyses. For players sustaining more than one ACL injury following baseline testing, we only included their first non-contact injury in the analyses.

Demographic data and baseline screening results were compared between players/legs with and without a new ACL injury by using chi-square tests for categorical data, Student`s t-test for continuous variables when the criterion of independency was fulfilled, or by conducting robust regression models to account for dependencies between legs. A new non-contact ACL injury was the main outcome. We calculated the odds ratios (OR) with 95% confidence intervals (CI) for players with and without an ACL injury history. For the final analyses the significance level was set at $P<.05$.

We followed a rigorous protocol with pre-defined procedures and variables of interest as described below. To ensure high statistical power, we decided to limit the number of primary variables (potential risk factors), and we generated 5 separate logistic regression models, one for each of the proposed risk factors; quadriceps, hamstrings, HQ-ratio, hip abduction, leg press (expressed as peak strength, normalized for body mass. New ACL injury was the outcome, using the leg as the unit of analysis. All models included the same set of adjustment factors to compensate for factors that could potentially influence injury risk: 1) sport, 2) dominant leg, 3) ACL injury history, 4) height, and if appropriate 5) isokinetic dynamometer. We calculated standardized odds ratios per 1 SD change with 95% confidence intervals for each risk factor and adjustment factor. In case there were significant associations between risk factor and outcome measure, we calculated receiver operating characteristic (ROC) curves to investigate the sensitivity and specificity characteristics of the particular variable (21).

To examine long-term changes in strength, we retested 144 players (aged 20.9±3.2 yrs) 1 to 5 yrs after the first test session (2.2±0.8 yrs). We calculated the mean difference, the standard method error (SEM) (the SD of the difference divided by the square root of two) and the intraclass correlation (ICC (3,1)) with 95% CI between test session 1 and 2 (5).

Results

A total of 867 players were included in the final analyses, 420 handball and 447 football players (Figure 1). During follow-up, through May 2015, we recorded 80 ACL injuries. Of these, 12 players had multiple ACL injuries (11 players with 2 injuries and one player with 3 injuries), which means that 67 players had at least one new ACL injury after baseline testing. Of the 67 index injuries suffered by these players, we recorded 9 as contact and 58 as non-contact/indirect contact. One of the players with a non-contact injury had to be excluded due to missing strength data, leaving us with 57 non-contact ACL injuries for analyses. The mean time between strength testing and a non-contact ACL injury was 1.8±1.8 yrs. Player demographics and injury history for prospectively ACL injured and uninjured players are presented in Table 1.

[Table 1 near here]

[Figure 1 near here]

Univariate risk analysis

Players with a new ACL injury did not differ significantly from those who remained free from ACL injury for any of the demographic or training history data. Almost every forth player with a history of previous ACL injury (3.5 ± 2.5 yrs before baseline screening) sustained a new ACL rupture (n=13, 23%); 4 of these re-ruptured the same knee and 9 suffered an ACL injury to the contralateral knee. The OR of sustaining a new ACL injury among those with a previous ACL injury compared to those with no ACL injury history was 3.14 (95% CI 1.61 to 6.12). A total of 31 players (54%) sustained a new ACL injury in their non-dominant leg, with no greater injury risk in the non-dominant compared to the dominant leg (P>.05). Among the 57 players who went on to suffer a new ACL injury there was no difference between their injured and uninjured leg for any of the 4 bilateral strength measurements (P>.05) Strength in the dominant and non-dominant leg did not differ between injured and uninjured players for any of the 4 strength measures (P>.05) (Table 2).

[Table 2 near here]

In a univariate comparison of strength, normalized to body mass, between injured and uninjured legs, significant differences were observed within the handball cohort, but not for the cohort at large when adjusted for leg dependencies (Table 3).

[Table 3 near here]

Multivariate risk analysis

The standardized ORs for each of the 5 multivariate logistic regression analyses are listed in Table 4. Adjusted for sport, dominant leg, ACL injury history, and height, none of the strength variables selected were significantly associated with a new ACL injury.

[Table 4 near here]

Change of strength variables over time (reliability study)

With an average time of 2.2 (SD 0.8) years between the 2 test-sessions, there were significant changes for leg press and hip abduction strength measures across test years (0-13%) (Table 5). ICC values ranged between 0.21 for isometric hip strength to 0.75 for isokinetic strength measures.

[Table 5 near here]

Discussion

The main findings of this prospective cohort study on female elite players do not lend support to low muscle strength being a risk factor for ACL injury. None of the 5 strength variables selected, isokinetic quadriceps, hamstring and HQ-ratio (all concentric at 60°/s), isometric hip abduction in supine position, and 1 repetition maximum in a seated leg press, were associated with an increased injury risk among female elite handball and football players. Neither isolated nor functional strength seem to play a role in ACL injury risk. Hence, the contribution of peak strength to ACL injury risk needs to be questioned. Our findings are supported by a recent nested, matched case-control study, where Vacek et al measured knee, hip and ankle strength in a group of high school and college athletes, concluding that none of these factors were significantly associated with ACL injury risk in a multivariate analysis (35).

Quadriceps and hamstrings strength and injury risk

Neither knee extension or flexion torques at 60°/s with the hip at 90°, nor a HQ-strength ratio were associated with ACL injury risk in the current study population. Corresponding findings were reported from a study on military academy cadets (33), whereas low strength and HQ-strength ratios were found to increase injury risk in female high school and college athletes (23). Hamstring and quadriceps forces will generate compression of the knee joint, which in turn stabilizes the joint and possibly reduces frontal and transverse plane movements, and joint translation (17). Thereby, in theory, ACL loads generated during sudden changes of direction, jumping and landing tasks can be counterbalanced. As there was no significant association between peak strength and injury risk in our cohort, it seems clear that increasing muscle strength will not reduce ACL injury risk. However, this does not necessarily mean that we should stop focusing on the role of muscles in ACL injury causation. It can be speculated that muscle activation patterns rather than strength could differ between injured and uninjured players, or that muscle support for some reason was insufficient in the injury situation due to inadequate activation. Given that a rapid recruitment of the hamstring and quadriceps muscles may be important for "unloading" the ACL from high ground reaction and tibial translation forces during foot contact (3), we should probably focus on muscle pre-activation rather than on peak strength.

Hip abduction strength and injury risk

Based on one prospective risk factor study assessing hip abduction strength on ACL injury risk (12) and on biomechanical understanding and the current literature, weakness in hip abductor strength are suggested to predispose an athlete to higher hip adduction and hip internal rotation, which in turn will lead to greater knee medial motion and knee abduction moments (11,32). Interestingly, in conflict with this hypothesis, we observed a borderline association between *greater* hip abduction strength, when normalized for body mass, and ACL rupture (P=.06). Reliability measures for hip strength were poor. Thus, these results should be interpreted with caution.

Female recreational athletes with greater hip external rotation strength combined with greater quadriceps and hamstring strength have been reported to exhibit a significant decrease in vertical ground reaction force during single-leg drop landings, and consequently less loading of the ACL (16). Despite of not having measured hip external rotation strength, we expected decreased, rather than increased, hip abduction strength to be associated with a subsequent ACL injury in our cohort. However, greater isometric external hip rotation strength has been found to be related to reduced frontal plane knee control during drop jumping in recreational female athletes (2), and in subjects who subsequently developed patellofemoral pain syndrome (6). Also, ACL-injured female athletes from the present cohort have displayed greater medial knee motion during a vertical drop jump task compared to uninjured controls (14). Based on these studies, it can by hypothesized that these players may have developed increased hip external rotation and hip abduction strength over time to counterbalance the increased dynamic knee valgus during dynamic tasks. This hypothesis needs to be confirmed in other cohorts.

Injury history, demographic factors and injury risk

The consistent identification of previous injury as a risk factor for a subsequent new injury highlights the importance of avoiding the first injury. In the current study, the odds for sustaining a new ACL injury in the group of players with an ACL injury history were tripled. Therefore, identifying intrinsic and extrinsic risk factors, also for recurrent ACL injuries, is significant when evaluating athletes, and specifically those with an injury history.

There are also investigations indicating that injuries increase the risk to sustain not just identical injuries, but also injuries to other body parts, most likely through changed motion patters and altered biomechanics (9). As we did not have consistent information available on injury history other than a previous ACL injury, we could not investigate the role of injuries in general on ACL injury risk.

Methodological considerations

We have to acknowledge several strengths and limitations of the present study when interpreting the findings.

With almost 900 female elite athletes tested, this prospective risk factor study is currently among the largest assessing potential associations between neuromuscular, biomechanical, and anatomical measurements and ACL injury risk. The strength variables selected for the present approach are in line with hypotheses taken from the literature to best address the current research question. Still, with 57 non-contact ACL injuries as the outcome measure, the study is not sufficiently powered to address more than 5 candidate risk factors including covariates at a time (1). As can be seen from the 95% confidence intervals, it is clear that none of the factors examined have strong associations with injury risk. In other words, increasing sample size would provide more precise odds ratios; yet they would still be clinically insignificant.

Moreover, we measured strength with standard measurement procedures widely used in clinical practice (8,32). However, it can be argued that ball game activities will include knee joint excursions with considerably higher velocity than the 60°/s we used for testing hamstrings and quadriceps strength. Alternatively, we could have measured knee extension and flexion strength at different angular velocities

As hip flexion typically is seen in landing situations to absorb forces, we also could have considered measuring hip abduction strength in side-lying (12) or with the hip flexed rather than extended to better mirror real-life motion patterns. It has been shown that different muscles are responsible for generating hip abduction force in a flexed hip compared with an extended hip (34). Moreover, we did not measure hip external rotator strength, which has been suggested to be associated with ACL injuries (12,16).

To address lower extremity strength more functionally in a closed kinetic chain, we decided to measure leg extension strength in a seated leg press machine.

As the majority of other investigations including strength measures, we chose to measure strength and torque values. However, peak torques may provide limited information about muscle performance during the full range of motion (8). Considering the need to develop sufficient muscle tension rapidly enough to provide dynamic joint stability, rate of force development and electromechanical delay measures could have been considered for the present purpose to identify ACL injury risk factors.

One obvious limitation with the current study is its length and the time between baseline strength testing and the main outcome measure, ACL injury: on average 1.8 years following testing. We do not have follow-up information available on player exposure to elite level play, their general injury history or strength training habits, that all may have changed over the course of the study and potentially could have influenced an individual´s risk for subsequent injury (22). We do have strength data from 144 players who have been tested twice over a 2-yr period. These repeated measures revealed strength changes from 0% for quadriceps and hamstrings strength and up to 13% for hip abduction strength. To reduce variability for potential changes in risk factors in the cohort, a subgroup-analysis of 23 players with an ACL injury within 1 year following screening revealed that this group had a lower HQ-ratio that the control group, but this injured group was also highly biased by having an ACL injury (5 of 23 players). Excluding those players from the analysis, the effect of a low HQ-ratio on injury risk disappeared".

Another limitation is that we relied on interviews with the athlete and medical staff to classify injuries as contact, indirect contact or non-contact. Recall bias and the ability to interpret what happened in an injury situation may be problematic. For this reason, we performed separate regression analyses with all prospective ACL injuries, contact and non-contact injuries, included. However, the outcome remained the same, documenting that potential misclassification of the mechanism of injury is not likely to change the results of this study.

Implications

Effective multifaceted exercise programs exist focusing on neuromuscular and plyometric components, as well as on trunk and lower limb stability to prevent knee and ACL injuries (18,24,28,36). Based on our findings, peak muscle strength does not seem to be of importance for ACL injury risk among female elite athletes. We do not know if our findings are generalizable to younger or lower level players, still, it may be questioned if strength exercises should be prioritized in multicomponent injury prevention programs. We furthermore know that injury prevention programs can be effective, even with minimal of strength training exercises. Following a one-season neuromuscular ACL injury prevention program focusing on knee control, technique and balance exercises, and previously proven to reduce injury risk among female elite handball players (24), players increased their muscle activation of the medial hamstring muscles prior to landing (39).

However, there may be other benefits of strength training exercises than pure muscle strength improvements. Combined training of strength, plyometric and balance exercises may contribute to improved muscle recruitment and neuromuscular control of lower limb joint stability thereby stimulating neuromuscular control rather than increasing maximal strength.

Conclusion

None of the lower extremity strength variables examined were associated with an increased ACL injury risk among female elite ball sport athletes. Hence, peak strength as measured in the present study, cannot be used to screen elite female athletes to predict injury risk.

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Figure legend

Figure 1: Flowchart of included and excluded players

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Conflict of interest

None of the co-authors declare any conflict of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine.