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ASSOCIATION BETWEEN LOWER EXTREMITY MUSCULAR STRENGTH AND ACUTE KNEE INJURIES IN YOUNG TEAM-SPORTS ATHLETES

Running head: Muscular strength and knee injury

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

ABSTRACT

The purpose of this study was to investigate LE muscular strength variables as potential risk factors for all and non-contact acute knee and ACL injuries in young athletes. A total of 188 young (≤21) male and 174 female basketball and floorball players participated in LE muscular strength tests and were followed up to three years. The strength test battery consisted of 1RM leg press, maximal concentric isokinetic (60°/s) quadriceps and hamstrings and maximal isometric hip abductor strength. The outcomes were a new acute knee or ACL injury and a new acute non-contact knee or ACL injury. A total of 51 (17 in males and 34 in females) new acute knee injuries registered and 17 (one in males and 16 in females) of these were ACL injuries. In the adjusted Cox regression models, only lower maximal hip abduction strength (kg/kg) was significantly associated with an increased risk of all knee injuries in males (HR 1.80 [95% CI, 1.03–3.16] for 1 SD decrease in hip abduction). However, ROC curve analysis showed an area under the curve 0.66 revealing that maximal hip abduction strength test cannot be used as a screening tool for an acute knee injury in young male athletes.

KEYWORDS: INJURY; LIGAMENT INJURY RISK; MUSCULOSKELETAL SYSTEM

1 INTRODUCTION

Knee injuries are one of the most common types of injuries in young athletes.[1,2] Knee ligament sprains are common acute knee injuries[1] with a rupture of the anterior cruciate ligament (ACL) as it most serious outcome often leading to long absence from or termination of sports, high risk of reinjury and early osteoarthritis.[3,4] Female athletes have higher risk of knee and ACL injuries than males.[1]

Most of the ACL injuries occur in non-contact situations such as landings, plant-and- cut movements or decelerations.[5] Increased knee valgus loading with tibial internal and/or external rotation seems to be the primary mechanism of these injuries.[5,6] Proper neuromuscular control in terms of strength, coactivation and recruitment of hamstring and quadriceps muscles is essential to maintain dynamic varus-valgus stability of the knee.[7] Decreased hamstring strength has shown to increase the estimated ACL-loading during anticipated sidestep cutting movements.[8] There is also evidence that impairments in trunk control is associated with knee and ACL injuries[9] and decreased hip abductor strength has shown to increase knee valgus angles in single leg squats and landings.[10,11] Thus, lower quadriceps, hamstrings or hip strength may contribute to increased risk of knee and ACL injuries but the results from the existing studies are conflicting and most of the studies mainly include adult athletes or focus on female athletes.[12-16] The role of lower extremity (LE) muscular strength as a risk factor for acute knee and ACL injuries is not conclusive.

Identifying factors that play a part in the occurrence of sport injuries is essential before planning injury prevention programmes.[17] Maximal LE muscular strength is a modifiable risk factor, which can be easily assessed in clinical setting. It increases with age in young athletes, especially in males over the age of 14 compared to females.[18] However, only few studies have investigated the association between maximal LE muscular strength and acute knee or ACL injuries in young athletes. In a recent case-control study, lower maximal one-repetition barbell squat strength was associated with acute knee and ACL injuries in young female but not in male athletes.[19] In another case-control study, decreased hamstring-to-quadriceps (HQ) ratio was related to increased risk of non-contact ACL injuries in female high school and collegiate athletes.[14] However, a nested and matched case-control study[20] revealed no associations between knee or hip muscle strength and non-contact ACL injuries neither in male nor female high school and collegiate athletes.

To our knowledge, there are no previous prospective studies on the relationship between LE muscular strength and acute knee and ACL injuries in young athletes. The purpose of this study was to investigate selected LE muscular strength variables as potential risk factors for acute knee and ACL injuries in young male and female team-sport athletes. We hypothesised that lower maximal muscular strength increases the knee and ACL injury risk in this population.

2 METHODS

2.1 Study design and participants

This study is part of the Predictors of Lower Extremity Injuries in Team Sports (PROFITS) study.[21] The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Pirkanmaa Hospital District, Tampere, Finland (ETL-code R10169). The participants signed a written informed consent before entering the study (including parental consent for participants under the age of 18).

Junior-aged (≤21) basketball and floorball players were recruited from 9 basketball and 9 floorball teams from 6 sports clubs from Tampere city district. All players played at the two highest junior or adult league levels. Inclusion criteria were: 21 years of age or younger, official team member and free from injury at baseline. Athletes were considered injury-free if they did not report injuries at baseline questionnaire and they were able to fully participate in baseline tests. Altogether 214 male (102 basketball and 112 floorball) players aged 16.1 ± 1.7 years (range, 13–20 years) and 189 female (107 basketball and 82 floorball) players aged 15.5 ± 2.0 years (range, 12–21 years) entered the study during the preseason (April-May) in 2011, 2012 or 2013. Each player completed a baseline questionnaire including questions about age, sex, starting age, previous injuries and playing experience. Baseline measurements of standing height (cm) and weight (kg) were recorded. The strength tests were maximal one-repetition seated leg press strength, maximal concentric isokinetic quadriceps and hamstrings strength (60°/s) and maximal isometric hip abductor strength. After baseline tests, injury registration continued until the end of April 2014. A total of 190 male and 178 female players completed the tests. Six (2 male and 4 female) players were excluded from the analyses, because they were not official members of the participating teams during the follow-up leading to a total of 188 male (93 basketball and 95 floorball) and 174 female (96 basketball and 78 floorball) players in the final analysis (Figure 1).

2.2 Muscular strength tests

The muscular strength tests were part of a baseline test battery used to investigate potential anatomical, biomechanical and neuromuscular risk factors for injuries. The complete test protocol with standardised warm-up procedures before each test is described elsewhere.[21]

2.2.1 Maximal one-repetition leg press strength

A seated leg press machine (Technogym®, Gambettola, Italy) was used to measure a combined maximal extension strength of LE muscles. The distance between feet was 20 cm and end of shoes were 10 cm above from the lowest end of the foot plate. The back of the seat was set on 30° angle relative to the floor. A vertical bar was placed at the point where the knees reached the target knee angle of 80° (Figure 2). The target knee angle was measured with a goniometer (HiRes, Baseline® Evaluation Instruments, White Plains, NY, USA). The one-repetition maximum (1RM) leg press test protocol started with 80–150 kg depending on player's weight bearing experience. At the starting point player's legs were extended and the weights were then lowered until the knees form the correct angle and then returned at the starting position as hard as possible. After each successful trial, the weights were increased by maximum 30 kg after the first trials and by minimum 10 kg after the last trials for the next attempt. Recovery period between the attempts was 2 minutes and the test ends when one-repetition maximum was reached. Body mass normalised value was used in the analysis. Similar test has been proved to be reliable tool for measuring muscular strength regardless of sex.[22]

2.2.2 Maximal isokinetic quadriceps and hamstrings strength

Maximal isokinetic quadriceps and hamstrings concentric strengths for both legs were measured at first study year (2011) in non-commercial dynamometer (Neuromuscular Research Center, University of Jyväskylä, Finland). At the second study year (2012) the dynamometer was replaced by Biodex Multi-Joint System Pro dynamometer (Biodex System 4, Biodex Medical Systems, Inc., Shirley, NY, USA). A test procedure was the same either of the dynamometers used. The test range of motion was 90° through 15° of knee flexion with an angular velocity of 60°/s (Figure 2). A standardised test protocol[21] with gradually increasing intensity were performed and the final test includes three repetitions with maximum power. The maximal strength was reported as peak torque (N·m) recorded and body mass normalised value was used in the analysis. Strength difference between legs as well as HQ ratio were calculated. Isokinetic strength testing has been established as reliable tool for assessing muscular strength.[23]

To evaluate the reproducibility of measurements between the used two dynamometers, twelve 14–15 years old male soccer players (24 legs) were tested with both dynamometers by different testers who collected the data. Intraclass correlation coefficient (ICC) value (3,k) was 0.81 (95% CI, 0.43–0.93) for isokinetic quadriceps and 0.79 (95% CI, 0.47–0.91) for isokinetic hamstring strength measurement meaning good test-retest reliability of the tests.

2.2.3 Maximal hip abductor strength

Maximal isometric hip abductor strength (kg) was tested with a hand-held dynamometer (Hydraulic Push-Pull Dynamometer, Baseline® Evaluation Instruments, White Plains, NY, USA). The test was perfomed with the player lying legs extended in a supine position on bench. The pelvis and the contralateral thigh were fixed with a belt and the player hold his or her arms across the chest during the test. The dynamometer was positioned approximately 2 cm proximal the lateral ankle malleolus with the leg in neutral position and the foot in slight dorsiflexion (Figure 2). The muscle contraction was hold for approximately two seconds. After one test trial the player performed two maximal contractions with a 10 second rest between the attempts. The better result was recorded and body mass normalised value was used in the analysis. In addition, strength difference between legs were calculated. Similar procedure has showed to have excellent intra-tester reliability with measurement variation 3 %[24] and acceptable inter-tester reliability with measurement variation 22%.[25]

2.3 Injury and exposure registration

During a follow-up period (May 2011–April 2014), all acute knee injuries were registered with a structured questionnaire. Two study physicians were responsible for collecting the injury data. They contacted the teams once a week to check possible new injuries and after each injury reported, the injured player was interviewed by telephone using the questionnaire. Injury definition was modified from definition by Fuller and colleagues.[26] An injury was recorded if the player was unable to fully participate in matches or training during the next 24 hours. Only injuries which occurred in a teams' scheduled training sessions or matches were included in this study. The injuries were classified as contact (ie. direct contact or strike to the involved knee) and non-contact (ie. no direct contact to the involved knee). All ACL injuries were verified by magnetic resonance imaging (MRI).

During the follow-up, the coach of each team recorded players' participation in trainings and matches. Player attendance in a training session (yes/no), duration of a training session (h) and attendance in each period of a match (yes/no) were recorded individually on a team diary. The diaries were returned after each follow-up month and the individual monthly exposure time (h) were registered for all players.

2.4 Statistical analysis

Descriptive data are presented as the mean ± standard deviation (SD) or the median and interquartile range (IQR) depending on the normality of distribution of variables. An independent-samples *t* test was used to compare group differences for normally distributed variables and the Mann-Whitney *U* test for non-normally distributed variables. Pearson's correlation coefficients were used to evaluate linear correlation between two variables. Injury incidences were calculated as the number of injuries per 1000 player-hours and reported with 95% CIs: ([*Incidence rate* – 1.96 * *Standard error of incidence rate*] * 1000 hours) to ([*Incidence rate* + 1.96 * *Standard error of incidence rate*] * 1000 hours). Results were calculated separately for male and female players and for all and non-contact knee and ACL injuries. Recurrent injuries were included in incidence calculations.

Cox regression models were used to analyse strength variables. The models were generated using the player as a unit of analysis or using the leg as a unit of analysis. The unit of analysis was defined according to strength variable representing either the characteristic of the player or of the leg.[27] The outcomes were a new acute knee or ACL injury and a new acute non-contact knee or ACL injury. The models were generated separately for males and females. Exposure time (h) from the start of the follow-up until the first injury or the end of the follow-up were included in the models. The exposure time of a month when an injury occurred were estimated by dividing the days from the beginning of the month to the injury date by all days of the month and then by multiplying the result by the registered total (playing and training) hours of the month. Sports club was included in all models as random effect and the leg in the models using it as the unit of analysis. Unadjusted and adjusted models with predefined adjustement factors were made for strength variables. The selected adjustement factors were previous acute knee injury and age as these might mostly influence to the risk of acute knee and ACL injuries.[17] These two adjustement factors were included in the models according to the amount of injuries in each model, using estimation of about 10 injuries needed per included variable (about 20 injuries, previous acute knee injury included and about 30 injuries, also age included).[28] In the models using the player as the unit of analysis, previous injuries of ipsilateral or contralateral side were included, and in the models using the leg as a unit analysis, only injuries of ipsilateral side were included.

Cox hazard ratios (HRs) per 1 SD increase with 95% CIs were calculated for each strength variable. *P* value < 0.05 were considered significant. A receiver operaiting characteristics

(ROC) curve analysis were calculated to assess the combined sensitivity and specifity of a test in cases where significant associations between the strength variable and the outcome were found. The test was defined as excellent (0.90–1.00), good (0.80–0.89), fair (0.70–0.79), poor (0.60–0.69) and fail (0.50–0.59). Statistical analyses were conducted in SPSS for Windows (v.20.0.0; SPSS), except the regression models, which were conducted in R (v3.1.2; R Foundation for Statistical Computing).

3 RESULTS

3.1 Baseline characteristics

Complete data were obtained from 188 (88%) male (93 basketball and 95 floorball) and 174 (92%) female (96 basketball and 78 floorball) players. As seen in Table 1, both male and female floorball players were significantly older compared with basketball players. Male floorball players had also higher BMI. Male floorball players had significantly more playing hours and female floorball players also training hours than their basketball counterparts. In addition, female floorball players had significantly more previous acute knee injuries than basketball players. The mean follow-up periods during the three study years were 1.3 ± 0.6 and 1.7 ± 0.6 years in males and females, respectively.

3.2 Injury characteristics

A total of 17 male (8 basketball and 9 floorball) and 29 female (9 basketball and 20 floorball) players sustained a new acute knee injury during the study. Five of these female players had both knees injured, thus 34 new knee injuries occurred in females. Two male and three female players had a re-injury to the same knee. An overall knee injury incidence for males and females was 0.3 (95% CI, 0.2–0.4) and 0.6 (95% CI, 0.4–0.8) per 1000 player-hours, respectively. Male players were on average 17.1 ± 1.3 (16.3 ± 1.0 in basketball and 17.9 ± 1.1 in floorball) and female players 16.5 ± 2.5 (14.1 ± 1.2 in basketball and 17.6 ± 2.2 in floorball) years at the time of first knee injury. Apart from ACL injuries, there were 5 contusions, 5 joint or ligament sprains, 3 meniscal lesions, 1 patellar dislocation, 1 intra-articular fracture and 1 unspecified injury in males and 7 contusions, 5 joint or ligament sprains, 1 meniscal lesion and 5 unspecified injuries in females.

A new non-contact knee injury was registered in 9 male (7 basketball and 2 floorball) and 25 female (7 basketball and 18 floorball) players. Two females had both knees injured, yielding 27 new non-contact knee injuries in females. One male and three females had a re-injury to the same knee. The incidence for non-contact knee injury for males and females was 0.2 (95% CI, 0.1–0.3) and 0.5 (95% CI, 0.3–0.6) per 1000 player-hours, respectively.

Fifteen female (3 basketball and 12 floorball) players sustained a new ACL injury. One female player had both knees injured, thus 16 new ACL injuries occurred in females. Fifteen of these 16 new ACL injuries in females occurred in non-contact situations. In addition, one female player had a re-injury to the same knee in a non-contact situation. An overall and non-contact ACL injury incidence was 0.3 injuries per 1000 player-hours (95% CI, 0.1–0.4) in females. Only one male player had an ACL injury (occurred in a non-contact situation) during the study period, thus incidence rates were not calculated and the risk factor analysis not made for male ACL injuries.

3.3 Unadjusted group differences

Unadjusted group comparisons revealed that male players who suffered any knee injury were 10 % (3.20 ± 0.62 vs 2.91 ± 0.55; P = 0.04) and female players 8 % (2.56 ± 0.43 vs 2.37 ± 0.38; P = 0.02) stronger than uninjured players measured by 1RM leg press strength (kg/kg) (Appendix 1 and 2). Similarly, in males who suffered a non-contact knee injury, 1RM leg press strength was 16 % (3.36 ± 0.48 vs 2.91 ± 0.56; P = 0.04) and in females 10 % (2.61 ± 0.41 vs 2.37 ± 0.38; P = 0.04) greater compared to uninjured players (Appendix 1 and 2). Also, in males who had a non-contact knee injury, maximal isokinetic quadriceps strength (N•m/kg) was 11 % greater in injured legs (2.86 ± 0.42) compared to uninjured legs (2.57 ± 0.42, P = 0.046) (Appendix 1). Moreover, maximal hip abduction strength (kg/kg) was significantly lower in males who had any (0.19 ± 0.05 vs 0.22 ± 0.04; P = 0.02) or a non-contact (0.19 ± 0.06 vs 0.22 ± 0.04; P = 0.02) knee injury compared to uninjured players (Appendix 1).

In female players who suffered any ACL injury, 1RM leg press strength (2.60 ± 0.28 vs 2.39 ± 0.39; P = 0.048) and between-leg difference in hip abduction strength (kg) [2.00 (1.00) vs 1.00 (2.00); P = 0.03] were significantly greater compared to uninjured players (Appendix 3).

3.4 Unadjusted risk factor analyses

In unadjusted Cox-regression models, the greater 1RM leg press strength was associated with an increased risk of non-contact knee injuries in males and females (HR for 1 SD increase, 2.30 [95% CI, 1.14–4.65]; P = 0.02 and 1.52 [95% CI, 1.04–2.21]; P = 0.03, respectively) (Table 2). There was a moderate correlation (r = 0.48, p < 0.001) between players' age and 1RM leg press strength in males and weak correlation (r = 0.31, p < 0.001) in females. Only very weak correlation existed between players' playing and practicing time and 1RM leg press strength in both males (r = 0.15, p = 0.04) and females (r = 0.19, p = 0.01). In males, the greater between-leg difference in isokinetic quadriceps strengths (N·m) was also associated with an increased risk of non-contact knee injury (HR for 1 SD increase, 1.85 [95% CI, 1.02–3.35]; P = 0.04). None of the strength variables were statistically significantly associated with female ACL injuries in unadjusted models (Table 3).

3.5 Adjusted risk factor analyses

Due to the low amount of non-contact knee injuries in males, adjusted risk factor analyses were not made for these male injuries. In females, the trend in 1RM leg press strength was similar as in the unadjusted models, but the observed diffrence was not statistically significant (HR for 1 SD increase 1.48 [95% CI, 0.97–2.26]; P = 0.07). In the adjusted models, only lower maximal hip abduction strength was associated with an increased risk of all knee injuries in males (HR 1.80 [95% CI, 1.03–3.16]; P = 0.04 for 1 SD decrease in hip abduction) (Table 2). However, ROC curve analysis for hip abduction strength test in males showed an area under the curve 0.66, indicating poor combined sensitivity and specifity of the test (sensitivity of the test 65 % and specificity 62 %). In females, none of the strength variables were statistically significantly associated with knee or ACL injuries in the adjusted models (Tables 2 and 3).

4 DISCUSSION

The purpose of this prospective study was to investigate the association between selected LE muscular strength variables as potential risk factors for all or non-contact acute knee and ACL injuries in young male and female team-sport athletes. The main finding was that lower maximal hip abduction strength was associated with increased risk of all acute knee injuries in young male basketball and floorball players, when adjusted for previous acute knee injury. Secondly, we found that none of the measured strength variables were associated with all or non-contact acute knee or ACL injury risk in young female players.

The findings concerning female players are supported by two prospective Norwegian studies, investigating the same strength variables: 1RM leg press strength, maximal isokinetic concentric hamstring and quadriceps strength at angular velocity of 60°/s, HQ ratio and maximal hip abduction strength measured with hand-held dynamometer.[15,16] Nilstad et al[15] studied a cohort of elite female soccer players and found no associations between any of these strength variables and all knee injuries. Steffen et al[16] studied partly the same elite female soccer player cohort as Nilstad and colleagues[15] and in addition to them, elite handball players, and reported either no associations between these strength variables and non-contact ACL injuries. Athough the players in the present study were considerably younger (15.4 years on average compared to 20.9 and 21.5 years in the Norwegian studies) and played mainly in junior-league matches, the selected muscular strength variables did not seem of significance alone in knee injury risk in females. However, separation between acute and overuse knee injuries were not made in Nilstad and others[15] study making direct comparisons to our study unreliable.

Also, Vacek and study group[20] found in a nested and matched case-control study no associations between maximal isokinetic quadriceps, hamstrings or isometric hip abduction strength and non-contact ACL injuries neither in female nor male high school and college athletes. ACL- injured players were 14–23 years with 75% of them between the ages of 15–20 years, but the measurement procedures, athought not descriped in detail, were different from ours. Vacek and colleagues[20] measured quadriceps and hamstrings strength with the knee at 15° and 30° flexion and hip abduction strength with a custom stabilization cage interfaced with a load sensor and force gauge.

A seated leg press, as a closed kinetic chain and multi-joint movement, was used to assess combined LE extension strength in the present study. It activates powerful LE muscles like gluteus maximus, quadriceps, hamstrings and gastrocnemius and have similarities to many athletic movements such as running and jumping.[29,30] Interestingly, the greater 1RM leg press strength was associated with increased risk of non-contact knee injuries in both male and female players in the unadjusted Cox-regression models. It could be assumed, that older players are stronger and they practise and play more even in adult league teams thus being more time at risk to get an injury. Very weak to moderate correlations between players' age or playing and practicing time and 1RM leg press strength indicates that age and exposure time alone are not sufficient enought to explain this finding. However, stronger players in this study might have been more mature and skilled otherwise. Strong players may also be able to run and change direction faster leading to greater mechanical forces and in this way the injury risk may increase. In addition, being strong does not necessarily mean that a player has a proper landing and direction change technique. Poor technique combined with greater muscle mass and higher speed may increase ligament loading and injury risk in strong players compared to weaker lightweighted players.

In contrast of our finding, Ryman Augustsson and Ageberg[19] studied also a cohort of young male and female athletes (aged 15–19) and found that lower 1RM barbell squat strength was associated with increased risk of all acute knee injuries in females but not in males. However, due to a greater quapriceps and hamstrings activity generated, tibiofemoral and patellofemoral compressive forces have shown to be generally greater in the squat than in the leg press exercise and this may provide enhanced knee stability during the squat exercise.[30] Thus, despite the great 1RM leg press strength, an athlete may not have such great knee stability and this may reflect to the increased risk especially for non-contact knee injuries.

Increased hamstring force during the knee flexion phase has shown to decrease relative strain on the ACL[31] and maximal isokinetic concentric hamstring strength has shown to remain steady with increasing maturational age in young female athletes while increasing in male athletes.[32] Thus, it could be assumed that low hamstring strength or HQ ratio might be a risk factor for acute knee and ACL injuries especially in young female athletes. However, we found no associations between isokinetic concentric quadriceps or hamstring strength or HQ ratio with all or non-contact acute knee injuries in males and females, and additionally, with all or non-contact ACL injuries in females. In line with our findings, Uhorchak and colleagues[33] reported no associations between maximal concentric or eccentric isokinetic strength at angular velocity of 60°/s and non-contact ACL injuries in a group of male and female military academy cadets in a 4-year prospective study. However, although the military cadets were relatively similar age (18.4 years on average compared to 15.8 years in our study) and participated in different sports and physical activities, the cadets' likelyhood to get an acute knee injury may not nesessarily be comparable with team-sport players in our study.

Myer et al[14] showed in a matched case-control study that female high school and collegiate soccer and basketball players who suffered a non-contact ACL injury had a combinaton of decreased maximal concentric isokinetic hamstring strength but not quadriceps strength compared to male controls. On the other hand, female controls who did not suffer a non-contact ACL injury, had decreased quadriceps but not hamstrings strength compared to male controls indicating that low HQ ratio may be the risk factor for non-contact ACL injuries in females. Although not mentioned, the female players in Myer and others[14] study could assume to be young and nearly similar age compared to the players in our study. In contrast, they measured maximal isokinetic concentric hamstring and quadriceps strength at much higher angular velocity of 300°/s. High angular velocities in isokinetic strength measurements can be speculated to correspond better to real injury situations in trainings and matches. However, the data from videoanalysis of ACL injury situations has showed that ACL injuries occur very fast, on average 40 ms after initial ground contact.[6] Thus, it is unlikely that the higher angular velocity in isokinetic strength tests explains the different findings in female players.

Increased hip abduction strength is thought to decrease knee loading and injury risk by counterbalancing hip adduction motion and subsequent knee valgus and abduction loads associated with acute knee and ACL injuries in female athletes.[11,34] We found no association between maximal hip abduction strength and all or non-contact acute knee or ACL injuries in young females, while in young males lower maximal hip abduction strength increased the risk for all acute knee injuries in the adjusted Cox-regression model. The reasons behind this finding are unclear. On the bases of the fact that maximal quadriceps and hamstring strength increases more in male athletes compared to females from ages 14 to 17 years,[18] maximal hip abduction strength may also increase greatly in male athletes in this age group. Thus, young male athletes, who have weak hip abductors, could also have an increased risk to knee valgus and abduction loads similar to female athletes[34] leading to the increased risk of acute knee injuries. However, the maximal hip abduction strength test we used had a poor combined sensitivity and specifity in the ROC curve analysis making it usage as a screening tool for an acute knee injury questionably.

Low hip abduction strength as well as hip external rotation strength have been previously found to associate with LE[35] and ACL[13] injuries in female and male athletes. Leetun et al[35] studied prospectively male and female varsity intercollegiate basketball players and cross-country athletes and found that both male and female players who sustain any back or LE injury were significantly weaker in hip abduction and external rotation compared to uninjured athletes. On the other hand, in Leetun and colleagues study[35], only 23% of injuries were knee injuries and only hip external rotation strength was the significant predictor of injury risk based on logistic regression analysis. Khayambashi et al[13] found in a prospective case-control study that decreased hip abduction and external rotation strength increased the risk of non-contact ACL injury in a group of male (on average 21.5 years) and female (on average 20.9 years) team-sport athletes. Although the data was not presented separately for males and females, it is noticeable, that the majority of the athletes and ACL- injured players in Khayambashi and others[13] study were males indicating that lower hip strength, in line with our study, increases the risk for acute knee and ACL injuries especially in males. In addition, this finding seems to be independent of players' age and maturity because our players were considerably younger. Although we found no associations between maximal hip abduction strength and non-contact knee injuries in males, this can purely be a result of the inadequate power of our study.

Although we found no association between LE muscular strength variables and the risk of acute knee or ACL injuries in young female athletes, it does not mean that strength excercises should be taken out of injury prevention programmes in this group of athetes. It should be noticed that we measured maximal muscular strength, while in neuromuscular injury prevention programmes, muscular strength training usually contains exercises with no additional weights concentrating on proper technique with gradually increasing volume and intensity.[36] A neuromuscular warm-up programme including bodyweight strength exercises has shown to be effective in the prevention of acute knee and ACL injuries in young female soccer players.[37] In addition, lower maximal quadriceps, hamstrings and hip external rotational strength are reported to increase the risk of overuse knee injuries in young female soccer players[38], and an exercise programme including strength training has shown to decrease the risk of anterior knee pain in male and female military recruits.[39] The mechanisms how strength training works are thought to be both direct (strengthening the certain muscles) and indirect (strength training related effect to improved coordination, enhanced techniques in playing situations, strengthening adjacent tissues and better psychological perception of high-risk situations).[36] Knee and ACL injury prevention programmes including muscular strength exercises are available for young athletes[37] and they are recommended to be included in regular training.

This study had several strengths including the relatively long follow-up, large sample size and low drop-out rate. In addition, prospectively collected injury and exposure data enabled the use of Cox regression analyses as the exact injury date and exposure time of each player were known. Moreover, the muscular strength variables were measured in this study with standard and simple procedures easy to use in clinical practice.

This study also had limitations. Only maximal muscular strength was measured in isokinetic quadriceps and hamstrings strength testing. Maximal strength may provide limited information about the muscle performance during the full range of knee motion. The largest quadriceps strength deficits have been established at knee flexion angles less than 40° after ACL injury.[40] In addition, maximal isokinetic quadriceps and hamstrings strength were measured in this study only with an angular velocity of 60°/s. It is obvious that much higher angular velocities are involved in knee movement patterns in ball-sports. Maximal hip abduction strength could have been measured also with the hip in flexion because in real injury situations the hip is usually in flexion rather than in extension. Also, despite the 3-year follow-up, the prevalences of knee and ACL injuries were relatively low limiting the statistical power of the study. Thus, we might not detect other than rather strong risk factors[27] and had to limit the amount of adjustement factors to maintain validity of the Cox regression analyses.[28]

In conclusion, our three-year-prospective study showed that lower maximal hip abduction strength is associated with increased risk of all acute knee injuries in young male team-sport athletes. However, according to the ROC curve analysis, this hip abduction strength test is a poor injury screening test for these athletes. Thus, maximal LE muscular strength as measured in the present study cannot be used as a screening tool for an acute knee injury in young male athletes.

5 PERSPECTIVES

The role of LE muscular strength concerning knee and ACL injuries is controversial and the study results concerning youth athletes are sparse. The purpose of this prospective study was to investigate the association between selected lower extremity muscular strength variables as potential risk factors for all or non-contact acute knee and ACL injuries in young male and female team-sport athletes.

Although we found that lower maximal hip abduction strength was significantly associated with increased risk of acute knee injuries in young male athletes, maximal hip abduction strength test could not be used as an injury screening tool for these athletes. Additionally, this study gave evidence that great maximal LE extension strength could, in fact, increase the risk of acute non-contact knee injuries in young athletes. None of the strength risk factors were associated with all or non-contact acute knee or ACL injuries in young female athletes.

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TABLE 1 Demographic data, exposure times an injury history in male (n = 188) and female (n = 174) players

	All (n = 188)	Basketball (n = 93)	Floorball (n = 95)	P- value	All (n = 174)	Basketball (n = 96)	Floorball (n = 78)	P- value
Age (y)[a]	16.0 ± 1.6	15.2 ± 1.6	16.8 ± 1.2	< 0.001	15.4 ± 2.0	14.6 ± 1.6	16.5 ± 1.9	< 0.001
Height (cm)[b]	178.6 ± 8.1	179.0 ± 9.6	178.2 ± 6.3	0.49	167.4 ± 6.2	168.2 ± 6.4	166.5 ± 5.7	0.08
Weight (kg)[b]	69.2 ± 10.9	68.6 ± 13.0	69.8 ± 8.3	0.44	61.0 ± 8.6	61.0 ± 9.5	61.1 ± 7.3	0.86
BMI, (kg/m²)[b]	21.6 ± 2.7	21.3 ± 3.0	22.0 ± 2.3	0.04	21.7 ± 2.7	21.5 ± 2.8	22.0 ± 2.5	0.24
Playing experience (y)[b]	8.1 ± 3.1	7.4 ± 3.2	8.8 ± 2.8	0.001	6.3 ± 2.5	6.4 ± 2.5	6.2 ± 2.5	0.43
Match exposure (h)[c]	10.4 (10.0)	8.0 (6.3)	13.3 (8.6)	< 0.001	10.1 (16.4)	7.3 (8.8)	19.9 (25.5)	< 0.001
Training exposure (h)[c]	288.2 (228.8)	294.7 (178.5)	284.4 (276.8)	0.53	252.0 (342.9)	203.3 (123.4)	478.6 (424.6)	< 0.001
Total exposure (h)[c]	298.9 (238.5)	300.0 (181.8)	297.8 (279.7)	0.44	258.9 (365.1)	214.1 (124.6)	500.6 (456.7)	< 0.001
Previous acute knee injury (n)[d]	43	26	17	0.10	43	18	25	0.04
Previous ACL injury (n)[d]	7	4	3	0.68	7	2	5	0.15

[a]Age at the start of the follow-up. Values are presented as mean ± SD.

[b]Values are presented as mean ± SD.

[c]Values are presented as median (IQR).

[d]Values are presented as total number of injuries.

TABLE 2 Unadjusted and adjusted HR (per 1 SD increase) with 95% Cis for strength variables for knee injuries in males and females[a]

	Male			Female			
	All knee injuries (n = 17)		Non-contact knee injuries (n = 9)	All knee injuries (n = 34)		Non-contact knee injuries (n = 27)	
	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)
Player as a unit of analysis							
Leg press (kg/kg)[b]	1.52 (0.92-2.49)	1.42 (0.79-2.54)[d]	**2.30 (1.14-4.65)**	1.35 (0.96-1.90)	1.23 (0.83-1.84)[e]	**1.52 (1.04-2.21)**	1.48 (0.97-2.26)[e]
Quadriceps between-leg differences (Nm)[c]	1.35 (0.85-2.15)	1.13 (0.72-1.77)[d]	**1.85 (1.02-3.35)**	0.72 (0.44-1.17)	0.74 (0.46-1.19)[e]	0.58 (0.33-1.04)	0.58 (0.34-1.01)[e]
Hamstring between- leg difference (Nm)[c]	1.15 (0.75-1.76)	1.14 (0.69-1.86)[d]	1.13 (0.63-2.03)	1.03 (0.72-1.48)	1.03 (0.69-1.53)[e]	0,98 (0.65-1.46)	0.95 (0.61-1.47)[e]
Hip abduction between-leg differences (kg)[c]	1.25 (0.81-1.93)	1.04 (0.69-1.57)[d]	1.06 (0.58-1.93)	1.02 (0.70-1.48)	1.08 (0.74-1.57)[e]	1.11 (0.76-1.61)	1.20 (0.82-1.76)[e]
Leg as a unit of analysis							
Quadriceps (Nm/kg)[b]	1.51 (0.92-2.49)	1.50 (0.88-2.57)[d]	2.00 (0.96-4.15)	0.96 (0.68-1.35)	0.92 (0.63-1.33)[e]	1.01 (0.69-1.48)	0.99 (0.66-1.49)[e]
Hamstrings (Nm/kg)[b]	1.20 (0.72-2.01)	1.04 (0.63-1.72)[d]	1.41 (0.68-2.90)	0.78 (0.54-1.13)	0.73 (0.49-1.09)[e]	0.87 (0.58-1.31)	0.83 (0.53-1.31)[e]
HQ ratio (%)	0.80 (0.49-1.33)	0.72 (0.42-1.24)[d]	0.68 (0.31-1.46)	0.75 (0.53-1.07)	0.76 (0.53-1.09)[e]	0.82 (0.55-1.22)	0.81 (0.54-1.22)[e]
Hip abduction (kg/kg)[b]	0.56 (0.31-1.01)	**0.56 (0.32-0.97)**[d]	0.65 (0.29-1.47)	1.01 (0.72-1.44)	1.04 (0.74-1.46)[e]	0.98 (0.66-1.46)	1.00 (0.68-1.48)[e]

[a]Values in parentheses are 95% CIs. Significant results are marked in bold. HQ ratio, hamstring to quadriceps ratio.

[b]Body mass normalized values.

[c]Difference between stronger and weaker leg.

[d]Adjustement factor: previous acute knee injury.

[e]Adjustement factors: previous acute knee injury and age.

TABLE 3 Unadjusted and adjusted HR (per 1 SD increase) with 95% Cis for strength variables for ACL injuries in females[a]

	All ACL injuries (n = 17)		Non-contact ACL injuries (n = 16)	
	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)
Player as a unit of analysis				
Leg press (kg/kg)[b]	1.57 (0.90-2.71)	1.51 (0.84-2.73)[d]	1.51 (0.86-2.65)	1.44 (0.78-2.64)[d]
Quadriceps between- leg differences (Nm)[c]	0.79 (0.42-1.47)	0.79 (0.44-1.40)[d]	0.75 (0.38-1.46)	0.75 (0.40-1.39)[d]
Hamstring between- leg difference (Nm)[c]	1.34 (0.84-2.15)	1.35 (0.82-2.22)[d]	1.25 (0.76-2.04)	1.25 (0.74-2.12)[d]
Hip abduction between- leg differences (kg)[c]	1.27 (0.86-1.87)	1.35 (0.91-1.99)[d]	1.27 (0.85-1.91)	1.36 (0.90-2.06)[d]
Leg as a unit of analysis				
Quadriceps (Nm/kg)[b]	1.06 (0.64-1.76)	1.11 (0.66-1.87)[d]	1.00 (0.59-1.69)	1.05 (0.61-1.80)[d]
Hamstrings (Nm/kg)[b]	0.94 (0.56-1.57)	0.99 (0.59-1.66)[d]	0.98 (0.58-1.66)	1.03 (0.60-1.76)[d]
HQ ratio (%)	0.89 (0.53-1.48)	0.90 (0.54-1.51)[d]	0.99 (0.57-1.70)	1.01 (0.59-1.74)[d]
Hip abduction (kg/kg)[b]	0.92 (0.56-1.54)	0.96 (0.58-1.61)[d]	0.88 (0.52-1.50)	0.92 (0.54-1.57)[d]

[a]Values in parentheses are 95% CIs. Significant results are marked in bold. HQ ratio, hamstring to quadriceps ratio.

[b]Body mass normalized values.

[c]Difference between stronger and weaker leg.

[d]Adjustement factor: previous acute knee injury.

FIGURE 1 The flow of players

FIGURE 2 A, The measurement of maximal one-repetition seated leg press strength. B, the measurement of maximal concentric isokinetic quadriceps and hamstrings strength; C, the measurement of maximal isometric hip abductor strength

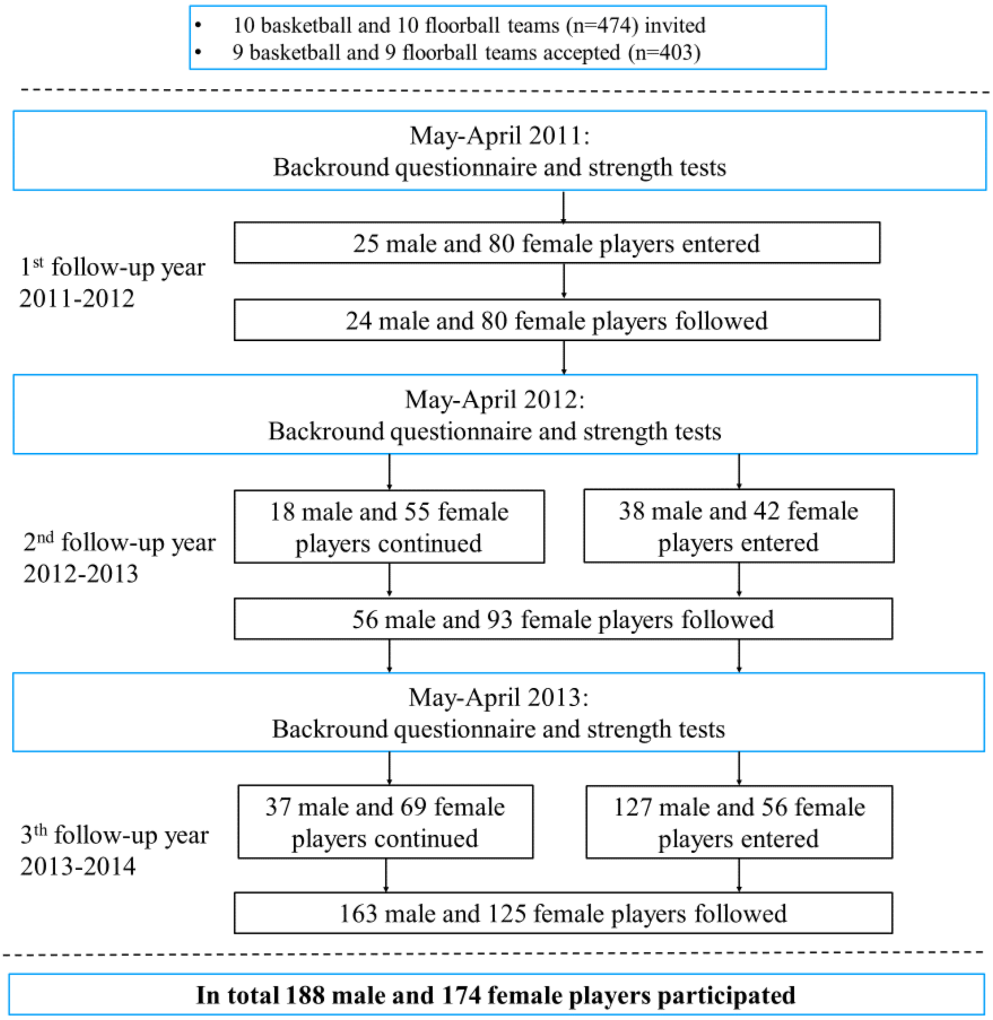
10 basketball and 10 floorball teams (n=474) invited
9 basketball and 9 floorball teams accepted (n=403)
May-April 2011:
Backround questionnaire and strength tests
1st follow-up year
2011-2012
25 male and 80 female players entered
24 male and 80 female players followed
May-April 2012:
Backround questionnaire and strength tests
2nd follow-up year
2012-2013
18 male and 55 female players continued
38 male and 42 female players entered
56 male and 93 female players followed
May-April 2013:
Backround questionnaire and strength tests
3th follow-up year
2013-2014
37 male and 69 female players continued
127 male and 56 female players entered
163 male and 125 female players followed
In total 188 male and 174 female players participated

FIGURE 2 A, The measurement of maximal one-repetition seated leg press strength. B, the measurement of maximal concentric isokinetic quadriceps and hamstrings strength; C, the measurement of maximal isometric hip abductor strength