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Stiff landings are associated with increased ACL injury risk in young female basketball and floorball players

ABSTRACT

Background: Few prospective studies have investigated biomechanical risk factors of anterior cruciate ligament (ACL) injury.

Purpose: To investigate the relationship between biomechanical characteristics of vertical drop jump (VDJ) performance and the risk of ACL injury in young female athletes.

Study Design: Cohort study.

Methods: At baseline, a total of 171 female basketball and floorball players (aged 12–21) participated in a VDJ test using 3D motion analysis. The following biomechanical variables were analyzed: 1) knee valgus angle at initial contact (IC), 2) peak knee abduction moment, 3) knee flexion angle at IC, 4) peak knee flexion angle, 5) peak vertical ground reaction force (vGRF), and 6) medial knee displacement. All new ACL injuries, as well as match and training exposure, were then recorded for 1 to 3 years. Cox regression models were used to calculate hazard ratios (HRs) and 95 % confidence intervals (CIs).

Results: Fifteen new ACL injuries occurred during the study period (0.2 injuries per 1 000 player hours). Of the six factors considered, lower peak knee flexion angle (HR for each 10° increase in knee flexion angle: 0.55; 95 % CI 0.34 to 0.88) and higher peak vGRF (HR for each 100N increase in vGRF: 1.26; 95 % CI 1.09 to 1.45) were the only factors associated with increased risk of ACL injury. A ROC curve analysis showed an area under the curve of 0.6 for peak knee flexion and 0.7 for vGRF, indicating a failed-to-fair combined sensitivity and specificity of the test.

Conclusions: Stiff landings, with less knee flexion and greater vGRF, in a VDJ test were associated with increased risk of ACL injury among young female basketball and floorball players. However, although two factors (decreased peak knee flexion and increased vGRF) had significant associations with ACL injury risk, the ROC analyses revealed that these variables cannot be used for screening of athletes.

Keywords: female; basketball; floorball; anterior cruciate ligament; biomechanics; screening; vertical drop jump

What is known about the subject: Young female athletes participating in sports involving running, pivoting, jumping and landing are at increased risk of ACL injury. Knee valgus plays a critical role in the mechanism of ACL injury. However, few prospective studies have investigated biomechanical risk factors of ACL injury, and only one study has found an association between knee valgus loading and future ACL injury.

What this study adds to existing knowledge: Stiff landings, with less knee flexion and greater vGRF are associated with ACL injuries in young female basketball and floorball players.

INTRODUCTION

Young female athletes participating in sports involving running, pivoting, jumping and landing are at increased risk of sustaining anterior cruciate ligament (ACL) injury.[1,51] According to recent research, adolescent athletes, who have sustained an intra-articular knee injury, are after 3–10 years more prone to have functional deficits, poorer quality of life, and are at increased risk of obesity compared to uninjured controls.[50] It is therefore essential to examine predisposing factors of ACL injury and to develop valid screening methods to identify athletes at risk.

Various studies have shown that knee valgus loading plays a critical role in the mechanism of ACL injury.[37,15,22,19,48] It is also well established that increased valgus motion is more common among female than male athletes.[14,17,22,26,16] So far, however, few prospective studies have investigated biomechanical risk factors of ACL injury[15,42,38,23] and, of these, only one small study has found an association between knee valgus loading and future ACL injury.[15]

In addition to frontal plane knee biomechanics, sagittal plane factors have been suggested to be related to ACL injury mechanism.[37,41,19,48] Stiff landings, i.e. landing with a low knee flexion angle, have been proposed to produce increased loading of the knee, and therefore predispose individuals to a greater risk of ACL injury.[6,7,40 ,33 ,46]

ACL injuries commonly occur in non-contact situation during direction changes, cutting maneuvers or when landing from a jump.[6,37 ,10,22,1,48,45] Different screening methods have been developed to assess dynamic knee control during sporting tasks. The vertical drop jump (VDJ) test simulates rebounding movements in basketball and is widely used for assessing knee alignment.[14,15,3,35,26] The test is easy to perform and can be used also without any measurement equipment.[34,44]

Hewett et al[15] utilized marker-based 3D motion analysis and reported that high knee valgus angle and abduction moment increase the risk of ACL injury in 205 young female athletes in mixed team sports. However, this study included only nine injured subjects, making it necessary to test their hypothesis in other cohorts.

Smith et al[42] recorded the motion with two ordinary video cameras (frontal plane and sagittal plane), and used the Landing Error Scoring System (LESS) to analyze kinematical characteristics of jump-landings in a large cohort of 5047 athletes (28 ACL injuries) from mixed sports. They found no relationship between the LESS score and future ACL injury. However, only the combined LESS score was reported, making it difficult to assess the individual variables, such as knee flexion angle and frontal plane knee motion. Recently, the LESS score was also studied in another cohort (829 athletes, 9 ACL injuries) of elite junior soccer players.[38] In this study, injured participants had higher LESS scores than uninjured participants, but due to a small number of injured athletes, assessment of individual landing errors was limited.

In a recent study, Krosshaug et al. [23] investigated VDJ kinetics and kinematics in 710 female elite handball and soccer players, of whom 42 went on to suffer a non-contact ACL injury in the study period. In this cohort, medial knee displacement during landing was associated with increased risk for ACL injury. However, receiver operating characteristic curve analysis indicated a poor combined sensitivity and specificity. Although the results from this study seem robust, we do not know if it can be generalized to other cohorts, such as younger, non-professional athletes.

Thus, the purpose of the study was to investigate selected biomechanical characteristics as potential risk factors for ACL injuries in young female basketball and floorball players.

MATERIALS AND METHODS

Study design and participants

The current investigation is a part of the PROFITS (Predictors of Lower Extremity Injuries in Team Sports) study. Detailed information on the PROFITS-study is described elsewhere.[39] The study was conducted in accordance with the Declaration of Helsinki, and was approved by Ethics Committee of the Pirkanmaa Hospital District, Tampere, Finland (ETL-code R10169).

Players were recruited from six basketball and floorball clubs of the Tampere City district, Finland. We invited players from the two highest junior league levels to participate in a baseline screening tests as a part of a prospective cohort study investigating risk factors for sports injuries. Female players who were junior-aged (≤21 years) and official members of the participating teams were eligible. Players signed a written informed consent form before inclusion (including parental consent for players aged <18 years).

The players entered the study either in 2011 (80 players), 2012 (29 players) or 2013 (62 players) (Figure 1). A total of 174 players successfully participated in the VDJ screening test. Following the start of screening tests, the players were followed for new ACL injuries through April 2014. Three players were lost to follow up, leading to a total of 171 players included in the final analysis.

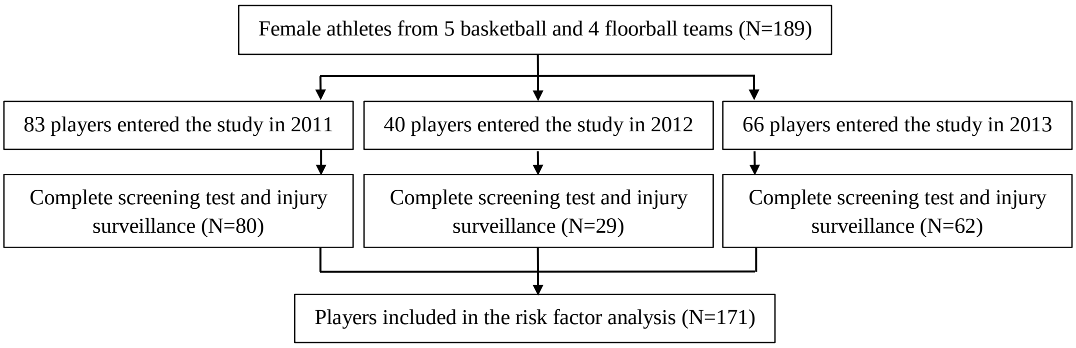

Figure 1. The flow of players in the study.

Test protocol

Each participant underwent a series of screening tests performed in our 3D motion analysis laboratory. One part of this test battery was a vertical drop jump task from a 30 cm box. The testing protocol was adopted from the risk factor study by Nilstad et al.[35]

The players wore tight shorts, sports bra and indoor sports shoes during the test. Height and weight, as well as knee and ankle joint widths were measured. Sixteen reflective markers were placed over anatomical landmarks on the lower extremities according to the Plug-In Gait marker set (Vicon Nexus v1.7; Oxford Metrics, Oxford, UK) (on the shoe over the second metatarsal head and over the posterior calcaneus, lateral malleolus, lateral shank, lateral knee, lateral thigh, anterior superior iliac spine, posterior superior iliac spine). All marker positions were carefully defined in our protocol. Two physiotherapists were trained for placing markers uniformly. One single physiotherapist placed markers on all players during the first two study years while another physiotherapist placed the markers during the third study year. Prior to the drop jump task, the subjects had performed a standardized warm-up procedure.

We instructed players to drop off a 30 cm box and perform a maximal jump upon landing with their feet on two separate force platforms (AMTI BP6001200; AMTI, Watertown, MA). Participants were instructed to practice the task up to three times. Three successful trials were collected from each participant. A trial was considered valid if the participant landed with one foot on each of the adjacent force platforms, performed a maximal vertical jump after the first landing, and the markers stayed firmly on the skin and were visible for cameras throughout the task.

Motion data collection

Eight high-speed cameras (Vicon T40, Vicon) and two force platforms (AMTI BP6001200; AMTI, Watertown, MA) were used to record marker positions and ground reaction force data synchronously at 300 and 1500 Hz, respectively. A static calibration trial was completed prior to task to determine the anatomical segment coordinate systems. Marker trajectories were identified with the Vicon Nexus software (Vicon Nexus v1.7; Oxford Metrics). Both movement and ground reaction force were filtered using a fourth-order Butterworth filter with cutoff frequencies of 15 Hz.[20] The landing phase was defined as the period when the unfiltered ground reaction force exceeded 20 N.

For each participant, six pre-defined biomechanical variables were calculated during the contact phase of the VDJ task. The following candidate risk factors were selected based on the current literature on factors associated with ACL injuries: 1) knee valgus angle at initial contact (IC), 2) peak knee abduction moment, 3) knee flexion angle at IC, 4) peak knee flexion angle, 5) peak vertical ground reaction force (GRF), and 6) medial knee displacement. Variables 1–5 were analyzed using the Plug-in Gait model (Vicon Nexus v1.7, Oxford Metrics).

Knee valgus angle at IC, peak knee abduction moment and medial knee displacement were chosen as measures of knee valgus loading. Knee valgus angle was designated as positive and knee varus as negative. The inverse dynamics approach according to the Plug-in Gait model was used to calculate knee joint moments. Positive knee abduction moment corresponded to external abduction moment, which tends to abduct the knee. Medial knee displacements were calculated from the 3D marker trajectories using a custom Matlab script (MathWorks Inc, Natick, Massachusetts, USA). The medial knee position was defined as the perpendicular distance from the knee joint center to the line determined by the hip and ankle joint centers in the frontal plane. The value of the medial knee position was determined to be positive only if the knee joint center was medially positioned to the line spanned by the hip and ankle joint centers. Otherwise, the medial knee position was set to zero. The medial knee displacement was then calculated as the difference between the medial knee position at its peak value and the initial foot contact.

Knee flexion angle at IC, peak flexion angle during the contact phase, and vertical GRF were chosen as measures of landing stiffness. A positive value in knee flexion corresponds to a flexed knee.

Injury and exposure registration

During the study period, five study physicians contacted the teams once a week to check possible new injuries. After each reported injury a study physician interviewed the injured player using a structured questionnaire. The definition of a new ACL injury was a MRI confirmed ACL rupture that occurred during a match or scheduled team training. Only noncontact injuries (i.e. no direct contact or strike to the involved knee) were included. A previous ACL injury was defined as an ACL injury of the ipsilateral or contralateral leg, of which the player was fully recovered from and had returned to sport before entering the study.

Exposure time during training and games was collected on a monthly basis. The coaches recorded player participation in practices and games using a team diary.

Statistical analysis

Descriptive data are presented as the mean ± standard deviation (SD). Independent samples t-tests were used to compare group differences. Injury incidence was calculated as the number of injuries per 1 000 player hours and reported with 95 % confidence intervals (CIs) [((incidence rate - 1.96 x standard error of incidence rate) x 1 000 hours) to ((incidence rate + 1.96 x standard error of incidence rate) x 1 000 hours)]. For measures of relative correlation between outcome variables, the Spearman Correlation Coefficient was calculated.

Six separate Cox mixed-effects models[47] with a new non-contact ACL injury as the outcome and the leg as a unit of analysis were generated. The monthly exposure time from the start of the follow up until the first ACL injury or the end of the follow up was included in the models. The mean of three jump trials was used for each biomechanical variable. Pre-defined adjustment factors that might influence the risk of injury were included in all six models: age, height, weight, sport, dominant leg, participation in adult league level matches, and previous ACL injury (a total of four previous injuries). Sports club and leg were included in all models as random effects. The dominant leg was defined the preferred leg when kicking a ball. Cox hazard ratios with 95 % confidence intervals (CI) were calculated. For improved interpretation, hazard ratios were adjusted for ten or hundred unit change. Variables that had a *P*-value less than .05 were considered significant. Statistical analyses were conducted in SPSS for Windows (v 20.0.0, SPSS Inc, Chicago, Illinois, USA), except the regression analysis which were conducted in R (v 3.1.2, R Foundation for Statistical Computing, Vienna, Austria).

Receiver operating characteristic (ROC) curve was calculated to investigate the sensitivity and specificity characteristics of a test based on the peak knee flexion and vertical GRF variables. The test outcome was defined as excellent (0.90–1), good (0.80–0.89), fair (0.70–0.79), poor (0.60–0.69), and fail (0.50–0.59).

RESULTS

Player and injury characteristics

Complete data for the baseline screening tests as well as the prospective registration of injury and match/training exposure were obtained from 171 athletes (96 basketball and 75 floorball players) (age 15.4 ± 1.9 years; height 167.7 ± 6.2 cm; body mass 60.8 ± 8.0 kg).

A total of 15 new non-contact ACL injuries were registered during the three seasons. In addition, there were two contact injuries, which were not included in the present analysis. One athlete suffered two separate ACL injuries (different legs), yielding to a total of 14 injured athletes (3 basketball and 11 floorball players). One injured athlete had a previous injury on the same side, and one injured athlete had a previous injury in the opposite knee. There were six dominant leg injuries and nine non-dominant leg injuries.

The total player exposure in training and match play was 58,927 hours throughout the three seasons. An overall ACL injury incidence was 0.2 injuries per 1 000 player hours (95 % CI, 0.1 to 0.4). Injury incidence in matches was 3.8 injuries per 1 000 hours of exposure (95 % CI, 1.3 to 6.3) and in training 0.1 injuries per 1 000 hours of exposure (95 % CI, 0.0 to 0.2). In basketball, all three ACL injuries occurred in matches (3.4 injuries per 1 000 hours of exposure). In floorball, the incidence for matches and training was 4.1 (95 % CI, 0.8 to 7.3) and 0.1 (95 % CI, 0.0 to 0.3) per 1 000 hours of exposure, respectively.

Biomechanical risk factors

There was a moderate correlation between the peak knee flexion angle and vertical GRF (-0.613, $P < .001$) (Table 1). There was no correlation between peak knee flexion and knee valgus angle at IC

(-0.039, *P*=.47) or abduction moment (-0.068, *P*=.21). Weak correlations existed between vertical GRF and knee valgus at IC (0.186, *P*=.001) and abduction moment (0.278, *P*<.001).

TABLE 1

Landing biomechanics in ACL injured group and uninjured group[a]

Variable	ACL injured knees (n=15)	Uninjured knees (n=327)	*P*-value
Knee valgus at IC (°)[b]	0.9 ± 5.8	-1.8 ± 6.7	.12
Peak knee abduction moment (Nm)	37.1 ± 24.9	31.2 ± 22.0	.32
Medial knee displacement (mm)	22 ± 18	26 ± 20	.47
Knee flexion at IC (°)	30.2 ± 11.7	27.6 ± 9.0	.29
Peak knee flexion (°)	81.5 ± 10.0	84.6 ± 10.3	.25
Peak vGRF (N)	1347 ± 403	1083 ± 321	<.01

[a] Values are presented as mean ± SD; IC, initial contact; vGRF, vertical ground reaction force.

[b] Positive value referring to valgus, negative value referring to varus alignment.

TABLE 2

Hazard ratios with 95 % CIs for six separate Cox regression models

		Adjustment factors						
Model	Risk factor	Age	Height (cm)	Weight (kg)	Dominant leg	Sport	Previous ACL injury	League level
1. Knee valgus at IC (°)	1.79[a] (0.71 – 4.55)	1.08 (0.77 – 1.51)	0.87 (0.76 – 0.98)	1.07 (0.98 – 1.17)	Yes 0.69 (0.24 – 1.95) No 1	Floorball 0.48 (0.03 – 7.19) Basketball 1	1.50 (0.27 – 8.20)	4.26 (0.98 – 18.56)
2. Peak knee abduction moment (Nm)	1.12[a] (0.91 – 1.39)	1.11 (0.79 – 1.56)	0.86 (0.76 – 0.97)	1.07 (0.98 – 1.17)	Yes 0.63 (0.22 – 1.84) No 1	Floorball 0.40 (0.03 – 5.71) Basketball 1	1.46 (0.27 – 7.94)	4.43 (1.02 – 19.25)
3. Medial knee displacement (mm)	0.99[a] (0.75 – 1.30)	1.10 (0.80 – 1.52)	0.86 (0.76 – 0.98)	1.07 (0.99 – 1.17)	Yes 0.68 (0.24 – 1.94) No 1	Floorball 0.38 (0.03 – 5.30) Basketball 1	1.45 (0.26 – 8.04)	4.76 (1.11 – 20.46)
4. Knee flexion at IC (°)	1.12[a] (0.63 – 2.00)	1.09 (0.80 – 1.51)	0.86 (0.76 – 0.97)	1.08 (0.99 – 1.17)	Yes 0.67 (0.23 – 1.91) No 1	Floorball 0.40 (0.03 – 5.66) Basketball 1	1.54 (0.28 – 8.53)	4.42 (1.01 – 19.41)
5. Peak knee flexion (°)	0.55[a] (0.34 – 0.88)	1.13 (0.81 – 1.57)	0.83 (0.73 – 0.94)	1.08 (0.99 – 1.17)	Yes 0.59 (0.21 – 1.69) No 1	Floorball 0.39 (0.03 – 5.76) Basketball 1	2.26 (0.35 – 14.75)	5.71 (1.35 – 24.22)
6. Peak vGRF (N)	1.26[b] (1.09 – 1.45)	1.16 (0.82 – 1.63)	0.86 (0.75 – 0.98)	1.02 (0.93 – 1.13)	Yes 0.45 (0.14 – 1.38) No 1	Floorball 0.42 (0.03 – 6.32) Basketball 1	1.79 (0.30 – 10.75)	4.24 (1.04 – 17.34)

[a] Hazard Ratio for 10 unit change; [b] Hazard Ratio for 100 unit change.

IC, initial contact; vGRF, vertical ground reaction force; ACL, anterior cruciate ligament.

In the Cox regression models (Table 2), peak knee flexion angle and peak vertical GRF were significantly associated with new ACL injury. High peak knee flexion angle decreased the risk of ACL injury (HR for each 10° increase in knee flexion angle: 0.55; 95 % CI 0.34 to 0.88; *P*=.01) whereas high vertical GRF increased the risk (HR for each 100 N increase in vertical GRF: 1.26; 95 % CI 1.09 to 1.45; *P*<.01). Knee valgus angle at IC (HR for each 10° increase in knee valgus angle: 1.79; 95 % CI 0.71 to 4.55; *P*=.22), knee flexion angle at IC (HR for each 10° increase in knee flexion angle: 1.12; 95 % CI 0.63 to 2.00; *P*=.70), peak knee abduction moment (HR for each 10 Nm increase in knee abduction moment: 1.12; 95 % CI 0.91 to 1.39; *P*=.27) or medial knee displacement (HR for each 10 mm increase in medial knee displacement: 0.99; 95 % CI 0.75 to 1.30; *P*=.94) were not significantly associated with the ACL injury.

Of the adjustment factors, lower height was a significant risk factor in all six models, and playing at adult league level in five of the six models. Age, weight, dominant leg, sport and previous ACL injury were not significantly associated with new ACL injuries (Table 2). In addition, body mass index (BMI) was tested, but not included in the final models. Replacing height and weight with BMI did not influence the results, and BMI had no significant association with injuries.

VDJ screening test characteristics

An ROC curve analysis for peak knee flexion showed an area under the curve of 0.6, indicating a failed-to-poor combined sensitivity and specificity of the test. For the vertical GRF variable, an area under the curve was 0.7, indicating a fair combined sensitivity and specificity. As shown in Figures 2 and 3, for both variables there was substantial overlap in the frequency distribution between injured and uninjured players.

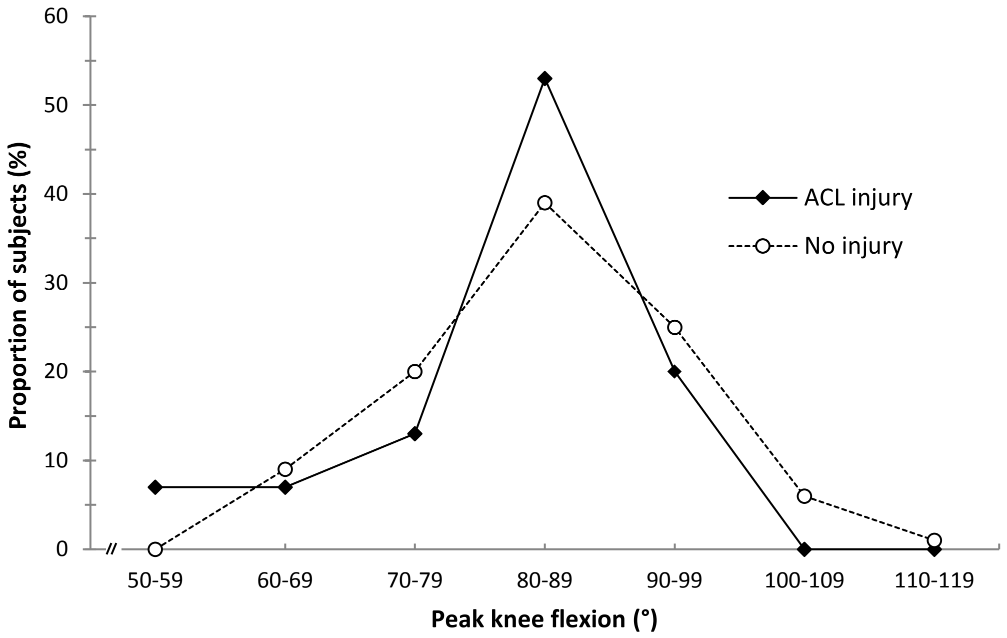

Figure 2. Frequency distribution of peak knee flexion for players with and without a new ACL injury.

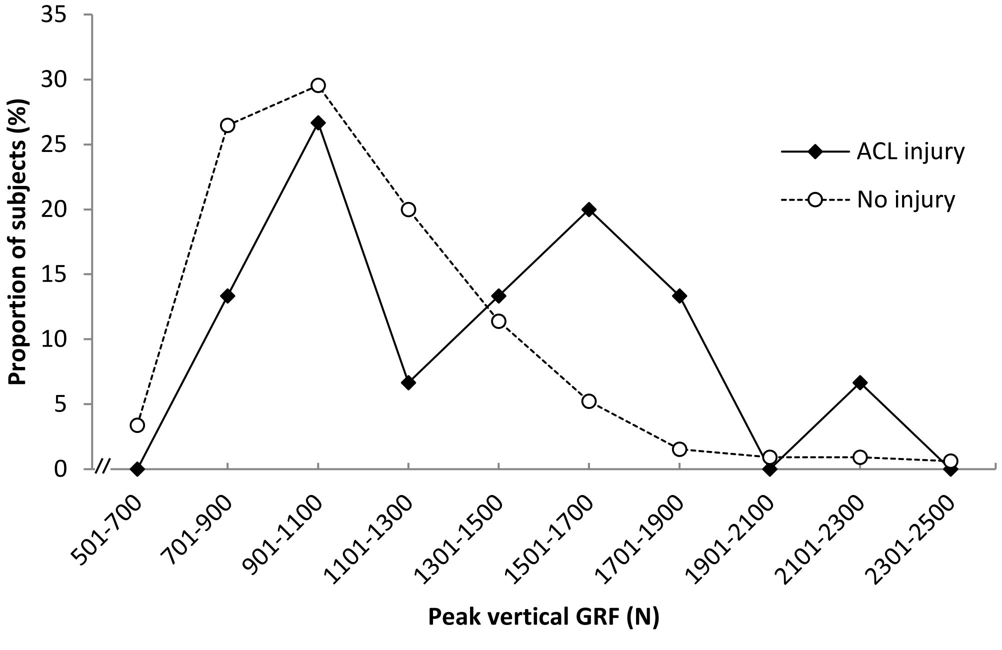

Figure 3. Frequency distribution of peak vertical ground reaction force (GRF) for players with and without a new ACL injury.

DISCUSSION

This prospective study showed that decreased peak knee flexion angle and increased vertical ground reaction force in a VDJ test were associated with an increased risk of ACL injury in young female team athletes. These findings support the current advice to avoid stiff landings.

Although many researchers have suggested that sagittal factors contribute to ACL injury,[9,37,8,33 ,19] the association between stiff landings and the risk of ACL injury has not been established in prospective studies. One study reported lower peak knee flexion angles and higher vertical GRF in ACL injured vs. uninjured females, but these factors were not significant in the regression analysis.[15]

The effects of sagittal plane knee motion on loading of the ACL has been studied by many investigations both *in vitro*[27,28,52,11] and *in vivo*.[4,5] There is evidence that a force placed on a nearly extended knee can lead to significant ACL strain[4,5,27] and even cause a rupture to the ACL.[11] Stiff landings are shown to produce higher vertical ground reaction forces[12,24,33] and knee extension moments[33] compared with a more flexed landing technique. Stiff landings are also suggested to cause greater stress on the ACL in relation to soft landing technique.[24,33] Weinhandl et al[49] investigated anticipatory effects on ACL loading in sidestep cutting. They reported that ACL force was significantly increased when performing the task without preplanning, and the increase in ACL loading was primarily due to an increase in sagittal plane loading. However, Myers et al[33] found that stiff landings did not produce significant increase in either anterior tibial translation, knee rotation or valgus movement, when compared with soft landings in healthy individuals under testing conditions. Our findings support the evidence that sagittal plane mechanics play a role in determining ACL loading, and that softer landing strategy may decrease the loading.

However, it should be noted that although the association with ACL injury is highly significant for both peak knee flexion angle and vertical GRF, there is substantial overlap between injured and uninjured players for both factors. The ROC analysis revealed an area under the curve of only 0.7 for vertical GRF and 0.6 for peak knee flexion, clearly demonstrating that none of these measures can be used as screening tests to predict ACL injuries.

Several studies have shown that knee valgus is an important component in noncontact ACL injury mechanism.[37,22,18,19,48] In the study by Hewett et al,[15] knee valgus angles (IC and peak values) were associated with ACL injury in female athletes. Although there was a similar trend with IC valgus angle in our study, neither of the variables measuring knee valgus motion or loading reached statistical significance.

There are some differences in the outcomes of interest in our study compared with three other risk factor studies available. Hewett et al[15] measured multiple variables, including hip joint motions. Similar to Krosshaug et al[23], our investigation included only a limited number of potential risk factors, but the outcomes were chosen based on factors purported to be associated with ACL injuries. In addition, there are differences in subject characteristics. Our study group was younger (15 years on average) and presumably less trained compared to the elite adult cohort of Krosshaug et al[23], and more similar to that of Hewett et al.[15] In our study, most of the participants played in junior leagues only, but some of the players (n=23) participated also in adult league matches. Playing at adult league level turned out to be a significant risk factor for ACL injury, probably due to a high total training and match load and higher physical demands on adult level.

ACL injuries typically occur in single-leg activities such as landing on one leg or side-step cutting.[37,22,48] It has been noted that athletes demonstrate different knee kinematics and kinetics in sport-specific cutting movements compared with drop-jumps.[21] Our study highlights the importance of sagittal plane motion in the assessment of a drop jump screening test. However, bearing in mind previous findings, it must be acknowledged that the double-leg drop jump test has limited value in predicting ACL injuries.[23] There is some evidence from studies investigating non-specific knee injuries that other measures, such as knee separation during a double-leg drop jump[36] or the combination of knee valgus and lateral trunk motion during a single-leg drop jump,[13] may be useful screening tools. In future studies, risk factors should perhaps be analyzed in more sports specific movements and in an environment where the athlete is less aware of being monitored and therefore might exhibit less controlled movements.

Strengths

The key strengths of this study are its relatively long duration and a high sample size with prospectively collected injury data. Athlete exposures were collected individually on a monthly basis and the coaches were contacted once a week for any new injury. This enabled the use of Cox regression analyses. We included only MRI confirmed ACL injuries. Also, the drop-out rate was low. Furthermore, we used 3D motion analysis method, which has been referred to as the gold standard for assessing lower extremity kinematics and kinetics.[29,34]

Limitations

A limitation of our marker-based motion analysis is that the kinematical calculations will be influenced by soft-tissue movement artifact.[25] Especially knee valgus measurements are affected by this.[43,30] Still, Nilstad et al[34] showed that there is a reasonable correlation between valgus angles and physiotherapist’s observations. Knee flexion, however, is a valid and accurate measure.[43] Furthermore, medial knee displacements and abduction moments will be less affected by the soft tissue artifact as the joint center estimation is much less sensitive to soft tissue artifacts than valgus angle calculation. Ground reaction force, measured with two force plates, is highly accurate. Finally, marker-based analyses are highly dependent upon marker placement.[32] In order to minimize inconsistency in marker placement, all marker places were carefully defined and two physiotherapists were trained for placing markers uniformly. A single physiotherapist was responsible for marker placement on all players each study year.

Furthermore, although we had a three-year follow-up, the prevalence of ACL injury was low thus limiting statistical power of the study. This means that the number of injury cases is too small to detect other than strong risk factors.[2] Statistical models were calculated separately for each variable. Using a combined model would have required a much higher sample size.

We decided not to exclude players with previous injury. However, we also ran the analyses including only players without previous injury and although there were two injured players less, the results were similar. In the final models, previous injury was included as an adjustment factor for both legs, since the previous injury may affect both the injured and uninjured leg.

CONCLUSION

This study showed that stiff landings, with less knee flexion and greater vertical ground reaction force are associated with increased risk of ACL injury among young female basketball and floorball players. Contrary to our expectations, we did not find any significant associations between frontal plane biomechanics and future ACL injury, possibly due to limited statistical power. Although the association with ACL injury was highly significant for both peak knee flexion angle and vertical GRF, the ROC analysis revealed that these measures cannot predict injury with sufficient accuracy.

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