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Risk factors for acute knee injury in female youth football

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ABSTRACT

Purpose: To prospectively evaluate risk factors for acute time-loss knee injury, in particular ACL injury, in female youth football players.

Methods: Risk factors were studied in 4,556 players aged 12-17 years from a randomised controlled trial during the 2009 season. Covariates were both intrinsic (body mass index, age, relative age effect, onset of menarche, previous acute knee injury or ACL injury, current knee complaints, and familial disposition of ACL injury) and extrinsic (no. of training sessions/week, no. of matches/week, match exposure ratio, match play with other teams, and artificial turf exposure). Hazard ratios (HRs) and 95% confidence intervals (CIs) were calculated from individual variable and multiple Cox regression analyses.

Results: 96 acute knee injuries were recorded, 21 of them ACL injuries. Multiple Cox regression showed a 4-fold higher ACL injury rate for players with familial disposition of ACL injury (HR 3.57; 95% CI 1.48-8.62). Significant predictor variables for acute knee injury were age >14 years (HR 1.97; 95% CI 1.30-2.97), knee complaints at the start of the season (HR 1.98; 95% CI 1.30-3.02), and familial disposition of ACL injury (HR 1.96; 95% CI 1.22-3.16). No differences in injury rates were seen when playing on artificial turf compared with natural grass.

Conclusions: Female youth football players with a familial disposition of ACL injury had an increased risk of ACL injury and acute knee injury. Older players and those with knee complaints at preseason were more at risk for acute knee injury. Although the predictive values were low, these factors could be used in athlete screening to target preventive interventions.

Level of evidence: II

Key words: ACL, epidemiology, female athlete, soccer, knee, prevention

2

INTRODUCTION

Football is the world's most popular sport with more than 265 million players according to the Big Count of the Féderation International de Football Association (FIFA) in 2006.[11] The injury rate is low for girls younger than 12 years playing 5- or 7-a-side football, but approaches that of senior players in older (teenage) females participating in 11-a-side football.[8, 13] Acute knee injuries, especially anterior cruciate ligament (ACL) injuries, are of particular concern for the adolescent female athlete participating in cutting and pivoting sports.[31, 35, 43]

Given the high injury rate in adolescent and senior female football players, injury prevention is of upmost importance. In order to properly design a preventive intervention, knowledge about the risk factors associated with injury occurrence is needed. Risk factors are traditionally divided into intrinsic (player related) and extrinsic (environmental) factors.[3] The majority of studies identifying or discussing potential risk factors for knee injuries in female football players have almost exclusively focused on ACL injury. Based on the findings from these studies, there seems to be a consensus that: (i) female sex is associated with a higher ACL injury rate,[1, 2, 4, 14, 15, 43] (ii) the ACL injury rate increases for girls in their adolescence,[4, 32, 34, 43] and (iii) the ACL injury rate is higher during match play compared with training.[4, 9, 14, 15, 17, 27, 43] In addition, previous ACL injury has been associated with a several-fold increased ACL injury rate in female elite players,[10] and the ACL injury rates in male and female collegiate football players were lower on artificial turf compared with natural grass.[14, 15] Few risk factor studies to date have used multiple variable analyses. In addition, the influence of intrinsic risk factors such as anthropometrics, maturation status and relative age effect, as well as extrinsic risk factors such as match

57　frequency and match play with older teams have not been well studied in football. The

58　objective of this study was therefore to evaluate risk factors for acute knee injury, in particular

59　ACL injury, in female youth football players using multiple analyses to account for the

60　influence of both intrinsic and extrinsic risk factors in tandem.

METHODS

This was a sub-study of a previous cluster randomised controlled trial (RCT) that evaluated

the preventive efficacy of a neuromuscular training program in female youth football. The

overall study design and the results of the intervention have been published.[18, 19, 41] The

main RCT showed a significant 64% reduction in the ACL injury rate in the intervention

group compared with the control group.[41] In the present sub-study, risk factors for acute

knee injury and ACL injury were investigated prospectively in the total study cohort (control

and intervention group clubs). This approach was chosen to increase statistical power of the

analyses, and as a result all analyses were adjusted for group belonging. Clubs were recruited

from the female U-14 to U-18 series (age 12 to 17 years) in eight regional districts of the

Swedish Football Association in 2009. The analysed sample included 230 clubs with 4,556

players; mean $\pm$ SD age 14.1 $\pm$ 1.2 years, weight 53.3 $\pm$ 8.6 kg, height 163.6 $\pm$ 6.7 cm, and

BMI 19.9 $\pm$ 2.5 kg/m^2. There are 24 regional football districts in Sweden and the included

sample is believed to be representative of the targeted age group.

Study procedures and outcomes

The data collection procedures and definitions used follow international guidelines for

football injury surveillance.[16, 20] Sixty-eight study physiotherapists and 8 study physicians

were recruited to serve as medical support to all clubs and assist the coaches with data

registration. Data were collected during a full competitive playing season (April 1 through

October 31, 2009). Injury surveillance included a baseline questionnaire with player variables

(intrinsic risk factors), a player attendance form with exposure variables (extrinsic risk

factors), and an injury report form. Each coach registered individual playing time (minutes of

participation for each player) and absences (due to acute knee injury or other reasons) for each

86 training session and match and sent the player attendance form by e-mail to the study

87 physiotherapist and study centre each month. If a player had additional playing time with a

88 district or national team, or another team within the club, this was also registered on the

89 player attendance form. Playing surface was documented for each exposure, as natural grass,

90 artificial turf or other (gravel, indoor). Acute knee injuries were reported by the coach as soon

91 as possible after the event to the responsible study therapist who evaluated the injury in

92 person and documented the injury. A recordable acute knee injury was one that occurred

93 during organised football training or match play, had a sudden onset, and led to a player being

94 unable to fully participate in future training or match play (excluding contusions).[19] Injury

95 severity was defined according to the number of lay off days from injury to return to full

96 training and availability for match play. Readiness to return to play was decided by the coach

97 and player together with the healthcare professional responsible for treatment/rehabilitation.

98 ACL injury was defined as a first-time or recurrent partial or total rupture of the ligament

99 either isolated or associated with concomitant injuries to the knee joint.[42] Players with

100 suspected ACL injury were routinely offered examination with magnetic resonance imaging

101 (MRI). If any information was missing or was unclear, the player, coach or study

102 physiotherapist was contacted for further clarification.

103

104 **Ethical approval**

105 The study was approved by the regional ethical review board in Linköping (Dnr M197-08).

106 Players and guardians gave individual written informed consent.

107

108 **Statistical analysis**

109 The primary outcome was the ACL injury rate and the secondary outcome was any acute knee

110 injury rate. Injury rates in match play vs. training, on artificial turf vs. natural grass, and

between the players' own team vs. other teams, were compared with a rate ratio (RR) and

95% confidence interval (CI), and P value was calculated with z-statistics.[28] The influence

of playing surface on injury rates was evaluated for training and matches with the players'

own team only. Comparison of injury distribution between the dominant and non-dominant

leg was made with a one sample z-test for proportions, assuming an equal proportion of 0.5.

Group comparisons (injured vs. uninjured players, players with vs. without exposure with

other teams) were made with one-way analysis of variance (ANOVA) for continuous

variables and the Chi^2 test for categorical variables.

Risk factor analysis was performed using Cox regression analysis, and presented as a hazard

ratio (HR) with 95% CI, and P value was calculated from the Wald's test. Covariates included

in the risk factor analysis were both intrinsic and extrinsic. Intrinsic variables were: body

mass index (BMI), age, relative age effect defined as being born in the first half of the

calendar year (yes/no), onset of menarche (yes/no), previous acute knee injury or ACL injury,

respectively (yes/no), current knee complaints at study start (yes/no), and familial disposition

of ACL injury among parents or siblings (yes/no). Extrinsic variables were: number of

training sessions per week, number of matches per week, match exposure ratio expressed as

match hours/total hours of exposure, match play with other teams (yes/no), and exposure to

artificial turf playing surface (yes/no). All continuous variables were dichotomised based on

the cohort mean value (below or above mean) before being entered into the analyses. In the

first step, individual variable Cox regression analyses were performed for all variables

separately, while all analyses were adjusted for group belonging (control or intervention

group) due to the previously identified preventive efficacy of the intervention.[18, 41] In the

second step, variables with $P < 0.20$ were then entered into a multiple Cox regression

analysis, again adjusting for group belonging. We checked for interaction effects between

136 group belonging and all covariates included in the multiple Cox regression analysis, and since

137 no significant interaction effects were present (all n.s.) no interaction terms were included in

138 the final models. The sensitivity, specificity, and positive and negative predictive values in

139 predicting new acute knee injury or ACL injury were calculated for variables that were

140 significant in the individual variable Cox regression analyses. All tests were 2-sided with a

141 significance level of $P < 0.05$. Analyses were made using IBM SPSS Statistics for Windows

142 (Version 21.0. Armonk, NY: IBM Corp.)

RESULTS

Knee injury characteristics and exposure

There were 96 acute knee injuries in 92 players (2.0% of players) during 278,298 hours of football (203,662 training; 74,636 match play). The acute knee injury rate was 0.35/1000 hours, being several-fold higher in match play than in training (1.09 vs. 0.074/1000 hours, RR 14.74, 95% CI 8.49-25.56, $P < 0.001$). Twenty-one players (0.5% of players) suffered 21 ACL injuries, giving an injury rate of 0.076/1000 hours. The ACL injury rate was almost 9-fold higher in match play compared with training (0.21 vs. 0.025/1000 hours, RR 8.73, 95% CI 3.20-23.86, $P < 0.001$). The characteristics of all acute knee injuries are presented in Table 1. As seen in Figure 1, the proportion of injured players tended to increase with higher age.

Player's own team and other teams

The majority of training (197,416 hours; 97%) and match exposures (67,993 hours; 91%) were registered with the players' own team. There were 1194 players (26%) who also had additional exposure with other teams, and they were older (14.3 ± 1.2 vs 14.0 ± 1.2 years, $P < 0.001$), played more matches (0.91 ± 0.31 vs 0.65 ± 0.27 per week, $P < 0.001$) and trained more often (1.41 ± 0.48 vs 1.25 ± 0.45 per week, $P < 0.001$) than players without additional exposure. Players with additional exposure incurred 11 injuries (all during matches; 2 ACL injuries) when playing with other teams, and 14 injuries (13 during matches; 3 ACL injuries) when playing with their own team. The acute match knee injury rate for these players was higher when playing with other teams compared with their own team (1.66 vs 0.61/1000 hours; RR 2.72, 95% CI 1.22-6.07, $P = 0.015$).

Playing surface and injury rates

168   Training surfaces were natural grass (166,938 hours; 85%), artificial turf (18,185 hours; 9%)

169   and other surfaces (12,292 hours; 6%), and for matches natural grass (60,622 hours; 89%),

170   artificial turf (5,800 hours; 9%) and other surfaces (1,571 hours; 2%). No differences in acute

171   knee injury rates were seen between artificial turf and natural grass in training (0.06 vs.

172   0.08/1000 hours, RR 0.66, 95% CI 0.09-4.99, n.s.) or match play (1.03 vs. 1.22/1000 hours,

173   RR 0.85, 95% CI 0.37-1.95, n.s.). The overall ACL injury rate did not differ between surfaces

174   (artificial turf 2; grass 19; both 0.08 ACL injuries/1000 hours, RR 1.00, 95% CI 0.23-4.29,

175   n.s.).

176

177   **Risk factors for acute knee injury**

178   Injury distribution in the dominant (n=44) and non-dominant (n=46) leg (6 injuries in

179   ambidextrous players excluded from analysis) did not differ from an expected equal

180   proportion (n.s.). More injured players reported onset of menarche, they were heavier and had

181   a higher BMI than uninjured players (Table 2). Older age, having knee complaints at baseline,

182   and familial disposition of ACL injury were significantly associated with an increased rate of

183   acute knee injury in the multiple Cox regression analysis (Table 3).

184

185   **Risk factors for ACL injury**

186   ACL injuries were more common ($P = 0.011$) in the non-dominant (n=11) compared with the

187   dominant leg (n=6); 4 ACL injuries in ambidextrous players were excluded from this analysis.

188   ACL-injured players had a higher mean age, higher mean weight, higher mean BMI and more

189   commonly reported ACL injury within the family than uninjured players (Table 2). Familial

190   disposition was associated with an increased ACL injury rate in the multiple Cox regression

191   analysis (Table 4).

192

Sensitivity, specificity, positive and negative predictive values

193

194   The sensitivity of significant variables from the individual variable Cox regression analyses to

195   predict new acute knee injury or ACL injury was generally low, ranging 17-87%, and the

196   specificity ranged 26-92% (Table 5). The positive predictive values ranged 1-4% and negative

197   predictive values were all ≥98%.

198

DISCUSSION

The main finding in this prospective study on risk factors for acute knee injury in female youth football players was that players with familial disposition of ACL injury had an almost 4-fold higher ACL injury rate. Furthermore, older players, those with knee complaints at the start of the season, and those with familial disposition of ACL injury had an increased rate of any acute knee injury in general. No differences in acute knee and ACL injury rates were seen when playing on artificial turf compared with natural grass.

Familial disposition of ACL injury

Female youth football players who had a parent and/or sibling with a history of ACL injury had an almost 4-fold increased ACL injury rate, and almost 2-fold higher rate of acute knee injury overall. Our prospective data thus tally with findings in previous case control studies reporting up to nine times higher prevalence of ACL tear among family members of ACL injured subjects compared with control subjects.[12, 21, 26] In addition, in a case series of 673 patients undergoing ACL reconstruction, those who had a first-degree relative with a ruptured ACL were almost twice as likely to sustain a graft rupture and contralateral ACL injury during follow-up.[5]

It cannot be deducted from the present study why players with familial disposition are at greater risk of ACL injury, but it has been suggested that factors related to increased risk of ACL injury (such as neuromuscular, biomechanical, anatomical, anthropometrical, and joint laxity characteristics) may be heritable in nature.[22] Another possible explanation is that genetic factors may contribute to an increased ACL injury risk[33] Although the present study, in line with previous work, suggest that heredity could be included as a non-modifiable

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224   risk factor to screen for in female youth athletes, it should be noted that familial disposition

225   had low sensitivity as a predisposing factor to ACL injury. Thus, the practical relevance for

226   screening in the youth female football population may be limited.

227

228   **Age and injury risk**

229   Older players (15 years or older) had an almost 2-fold increased rate of acute knee injury and

230   a similar, but non-statistically significant, increased rate of ACL injury. A higher proportion

231   of injured players (acute knee injury and ACL injury) also reported onset of menarche,

232   although menstrual status was not significantly associated with injury in the regression

233   models. Pubertal stage has previously been linked to sports injury risk, with increased risks

234   observed in Tanner stages 4 and 5 compared with stages 1 and 2.[30] A decrease in

235   neuromuscular control about the knee for female athletes with maturation has been suggested.

236   For example, Hewett et al.[23] showed that late pubertal or post-pubertal female athletes

237   (Tanner stages 4 and 5, mean age 15.5 years) had greater medial knee motion in a drop

238   vertical jump test compared with early pubertal (Tanner stages 2 and 3, mean age 12.6 years)

239   and pre-pubertal (Tanner stage 1, mean age 11.5 years) females. Further, girls demonstrate

240   poorer neuromuscular adaptations to the musculoskeletal changes that accompany maturation

241   than boys,[23] possibly explaining the observed increased rate of acute knee ligament injury

242   in late pubertal and postpubertal females. Similarly, post-menarche female artistic elite

243   gymnasts (mean age 19.1 years), as compared with pre-menarche athletes (mean age 11.6

244   years), display greater maximum knee abduction angle and knee abduction moment during a

245   one-legged drop jump test.[25] Greater knee abduction angles and moments have previously

246   also been found to associate with future ACL injury risk.[24]

247

248   **Leg dominance and injury risk**

249 A higher prevalence of ACL injury was observed in the non-dominant (supporting) leg, which

250 is similar to findings in a previous retrospective study on female footballers (mean age at

251 injury 20.4 years) where 68% of non-contact ACL injuries occurred to the non-dominant

252 leg.[6] It has been hypothesised that female athletes may be more limb dominant than males,

253 showing, for example, a higher prevalence of side-to-side imbalances in muscular strength

254 and joint kinematics.[31] One might thus speculate that differences in neuromuscular control

255 between limbs, or a greater exposure to high-risk one-legged loading patterns on the non-

256 dominant limb (e.g. during shooting or passing, or during cutting manoeuvres) can contribute

257 to an increased injury risk.

258

259 **Previous injury and current complaints**

260 In female elite players, previous ACL injury has been associated with a 5-fold increased ACL

261 injury rate.[10] Only 0.9% of our study sample reported a previous ACL injury at baseline,

262 and none in the subsequently ACL-injured group, and it was therefore not possible to

263 conclude on previous ACL injury as a risk factor in this study. However, a higher proportion

264 of players with previous acute knee injury, as well as current knee complaints, at baseline was

265 observed in players who sustained an acute knee injury during the season. Previous knee

266 injury and lower knee-related function and presence of symptoms at study start, based on the

267 Knee injury and Osteoarthritis Outcome Score (KOOS), have previously also been reported to

268 predict new knee injury in female adolescent football players.[7, 39] However, in line with the

269 latter study,[39] the sensitivity in predicting future acute knee injury was low (17%) and with

270 a positive predictive value of only 4%.

271

272 **Extrinsic factors and injury risk**

273   The ACL injury rate was almost 9-fold higher, and the overall acute knee injury rate 15-fold

274   higher, in match play compared with training. This is in line with previous studies,[4, 9, 14,

275   15, 17, 27, 43] and shows the higher risk involved in football match play. Noteworthy is that

276   ACL injury was a rare occurrence in our population of female youth football players,

277   affecting less than 0.5% of all players in a season, with 0.28% and 0.67% in the intervention

278   and control groups, respectively.[41] Our findings are similar to those previously reported

279   from Norwegian female youth football (mean age 15.4 years) where 11 of 2020 players

280   (0.5%) suffered an ACL tear during a season,[38] and where 10 of 11 ACL injuries occurred

281   in matches. This suggests that ACL injuries are not an epidemic in youth female football, and

282   that football training is a fairly low risk activity from a knee injury perspective. The season

283   incidence of ACL injury in senior female elite football is considerably higher (3-6%),[43]

284   indicating that the risk increases with higher age and higher levels of play.

285

286   Exposure to artificial turf playing surface was not a risk factor for acute knee injury or ACL

287   injury in the present study. A previous study on youth female football players showed no

288   overall difference in injury rates between artificial turf and grass, while the injury subtypes

289   knee injuries and ligament injuries were more common on artificial turf.[38] The incidence of

290   ACL injury, however, was not statistically significant between surfaces, although limited by a

291   very small sample (three on grass, four on artificial turf). Another study from boys' and girls'

292   adolescent football showed no difference in knee injury rates between artificial turf and

293   grass.[36] Other studies from male and female collegiate football players found that the ACL

294   injury rates were lower on artificial turf compared with natural grass,[14, 15] or similar

295   between surfaces.[29] Although the present study, and most other previous studies, suggest

296   that artificial turf is a safe (equal to natural grass) football playing surface from a knee

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297 ligament injury perspective, more information on the influence of playing surface, weather

298 conditions and the shoe-surface interaction and knee injury risk is warranted.

299

300 Finally, it has been a concern that young talented female players who play additional matches

301 with other teams than their own team, e.g. with the senior team of the club[35] or with

302 national teams, are more prone to suffer an acute knee injury. One-fourth of players in the

303 present study had other team exposures and they were older and played more matches than

304 those who only played with their own team. They also had an increased match injury rate

305 when playing with other teams than their own team. However, the proportion of injured

306 players was not different between those who played with other teams and those who did not,

307 and exposure to match play with other teams was not associated with acute knee injury or

308 ACL injury in the risk factor models. Moreover, no association between the weekly load of

309 training sessions and matches, or the ratio of match play and training exposure, and knee

310 injury risk was found in this study. A recent Danish study showed that neither the level of

311 play nor the match/total exposure ratio were associated with the risk of any time-loss injury in

312 adolescent female football players, and that a high weekly average exposure was associated

313 with a lower injury risk.[8] In contrast, Soligard et al.[37] reported that high-skilled players

314 had an overall higher injury rate than low-skilled players, and the authors speculated that

315 these players are more highly involved in matches, and more prone to tackles and foul play,

316 which could increase injury risk. However, no details on exposures with other teams were

317 presented in that study, and direct comparison with our findings is therefore difficult. Clearly,

318 more research on the influence of training and match load, including exposures with older

319 youth teams and senior teams, and injury risk is needed before solid recommendations can be

320 made. In the meantime, it seems reasonable to limit the exposure to match play with older

16

321 youth teams and senior teams for young girls playing football, given the higher injury rate

322 observed during these additional exposures.

323

324 **Study strengths and limitations**

325 Some strengths of the present study include the large sample involving more than 4,500

326 participants and individual playing time registration with no missing data for analysed clubs.

327 Additionally, the medical support supplied through the study enabled quick and qualified

328 examination of injuries by experienced sports medicine practitioners including a liberal policy

329 for MRI referral, and it is therefore unlikely that any ACL injuries have been overseen.

330

331 This study also has some limitations. Low seasonal ACL injury and acute knee injury rates

332 meant that some analyses suffer from a lack of power. As a rule of thumb, 10 outcome events

333 per predictor variable (EPV) is often recommended for Cox regression, although it has also

334 been suggested that models with 5-9 EPV could be sufficient.[40] In the multiple Cox

335 regression models, we had 3.5 EPV for ACL injury, and 11.5 EPV for acute knee injury, and

336 the results from the ACL injury risk factor model should be interpreted with some caution. To

337 increase statistical power in this study, and like procedures used in previous similar

338 studies,[37-39] we included also the intervention group teams/players from the original

339 RCT.[41] As a result, all risk factor analyses were adjusted for group belonging, and we also

340 checked for interaction between group belonging and all predictor variables included in the

341 multiple models (all were n.s.). Even so, it is likely that the neuromuscular training

342 intervention has influenced other potential risk factors not included in the present study, such

343 as neuromuscular control, and these factors may also correlate with our measured risk factor

344 variables. As previously discussed, neuromuscular control about the knee varies with

345 maturation status in female athletes,[23, 25] and is related to knee injury risk,[24] and thus, a

346 sufficiently sized prospective study in a sample of athletes receiving no intervention would

347 have been optimal.

348

349 **CONCLUSION**

350 This prospective study on female youth football players showed that familial disposition of

351 ACL injury, older age (15 years or older), and having knee complaints at the start of the

352 season were factors that predisposed to an increased acute knee injury risk. Although the

353 predictive values were low, these factors could be used in athlete screening to target

354 preventive interventions.

355

356 **ACKNOWLEDGEMENTS**

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367

368 **CONFLICT OF INTEREST**

369 The authors declare they have no conflict of interest.

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TABLE AND FIGURE LEGENDS

TABLE 1 Acute knee injury characteristics in female youth football players

Footnotes

ACL, anterior cruciate ligament.

[a] Reported diagnoses (multiple diagnoses per injury event possible) of knee injuries were medial collateral ligament sprain (n=28), capsular sprain (n=26), ACL tear (n=21), patella dislocation/subluxation (n=13), meniscus tear (n=12), lateral collateral ligament sprain (n=8), cartilage lesion (n=4) and fracture (n=2).

[b] As reported at up to 1 year follow-up after injury.

TABLE 2 Baseline characteristics and exposure data for uninjured players, and players sustaining acute knee injury or ACL Injury

Footnotes

ACL, anterior cruciate ligament; BMI, body mass index.

a P value from significance testing with ANOVA (continuous variables) or the Chi2 test (categorical variables).

b Exposure data are reported up to first injury event (injured players) or during entire season (uninjured players).

c Match hours/total hours of exposure.

d Number of players who played matches with a district or national team or older youth/senior team within the club during study inclusion.

TABLE 3 Risk factors for acute knee injury based on Cox regression analysis

Footnotes

BMI, body mass index; CI, confidence interval.

a All analyses adjusted for group belonging (intervention or control group)

b Variable dichotomised according to below or above cohort mean.

c Match hours/total hours of exposure.

d Variables with P < 0.20 in individual variable analysis were entered into multiple analysis.

TABLE 4 Risk factors for ACL injury based on Cox regression analysis

Footnotes

ACL, anterior cruciate ligament; BMI, body mass index; CI, confidence interval.

a All analyses adjusted for group belonging (intervention or control group).

b Variable dichotomised according to below or above cohort mean.

c Match hours/total hours of exposure.

d Variables with P < 0.20 in individual variable analysis were entered into multiple analysis.

TABLE 5 Sensitivity, specificity, positive and negative predictive values of variables to predict new acute knee injury or ACL injury.

Footnotes

ACL, Anterior cruciate ligament; BMI, Body mass index; PPV Positive predictive value; NPV Negative predictive value

FIGURE 1 Injury proportions by age group

TABLE 1
Acute knee injury characteristics in female youth football players

	Acute Knee Injuries (n=96)	ACL Injuries (n=21)
Activity		
Training	15 (16%)	5 (24%)
Match play	81 (84%)	16 (76%)
Injury mechanism		
Contact	53 (55%)	8 (38%)
Noncontact	43 (45%)	13 (62%)
Leg dominance		
Dominant leg	44 (46%)	6 (29%)
Nondominant leg	46 (48%)	11 (52%)
Player ambidextrous	6 (6%)	4 (19%)
Severity		
1-7 days absence	10 (10%)	-
8-28 days absence	29 (30%)	-
>28 days absence	57 (59%)	21 (100%)
Surface		
Grass	88 (92%)	19 (91%)
Artificial turf	7 (7%)	2 (10%)
Other	1 (1%)	-
Recurrence		
Yes	8 (8%)	-
Injury situation		
Playing with own team	85 (89%)	19 (91%)
Playing with older youth team	5 (5%)	1 (5%)
Playing with senior team	6 (6%)	1 (5%)
Diagnostics[a]		
Radiograph	33 (34%)	13 (62%)
MRI	34 (35%)	17 (81%)
Arthroscopy	11 (11%)	6 (29%)
Treatment[b]		
Nonsurgical	79 (82%)	8 (38%)
Surgical	17 (18%)	13 (62%)

ACL, anterior cruciate ligament.

[a] Reported diagnoses (multiple diagnoses per injury event possible) of knee injuries were medial collateral ligament sprain (n=28), capsular sprain (n=26), ACL tear (n=21), patella dislocation/subluxation (n=13), meniscus tear (n=12), lateral collateral ligament sprain (n=8), cartilage lesion (n=4) and fracture (n=2).

[b] As reported at up to 1 year follow-up after injury.

TABLE 2

Baseline characteristics and exposure data for uninjured players, and players sustaining acute knee injury or ACL injury

Variable	Acute knee injury			ACL injury		
	No (n=4472)	Yes (n=92)	P value[a]	No (n=4543)	Yes (n=21)	P value[a]
Mean (SD) age (years)	14.1 (1.2)	14.5 (1.3)	0.001	14.1 (1.2)	15.0 (0.9)	0.001
Age distribution (years)						
12	272 (6%)	3 (3%)		275 (6%)	0	
13	1413 (32%)	20 (22%)		1432 (32%)	1 (5%)	
14	1312 (29%)	23 (25%)		1330 (29%)	5 (24%)	
15	868 (19%)	27 (29%)		885 (19%)	10 (48%)	
16	424 (9%)	11 (12%)		431 (9%)	4 (19%)	
17	183 (4%)	8 (9%)		190 (4%)	1 (5%)	
Born first half of year, yes	1741/4472 (39%)	40/92 (43%)	n.s.	1768/4543 (39%)	13/21 (62%)	0.031
Mean (SD) height (cm)	163.6 (6.7)	164.6 (6.2)	n.s.	163.6 (6.7)	165.9 (5.8)	n.s.
Mean (SD) weight (kg)	53.3 (8.5)	55.2 (7.9)	0.036	53.3 (8.5)	58.2 (8.5)	0.011
Mean (SD) BMI (kg/m^2)	19.9 (2.5)	20.4 (2.3)	n.s.	19.9 (2.5)	21.1 (2.3)	0.027
Menarche, yes	3123/4199 (74%)	77/89 (87%)	0.009	3180/4267 (75%)	20/21 (95%)	0.030
Previous acute knee injury, yes	360/4315 (8%)	16/92 (17%)	0.002	373 (9%)	3/21 (14%)	n.s.
Previous ACL injury, yes	38/4316 (0.9%)	1/92 (1.1%)	n.s.	39/4387 (0.9%)	0/21	n.s.
Current knee complaints, yes	1052/4315 (24%)	35/92 (38%)	0.003	1082/4386 (25%)	5/21 (24%)	n.s.
Familial disposition ACL injury, yes	633/4211 (15%)	23/90 (26%)	0.006	648/4280 (15%)	8/21 (38%)	0.004
Exposure[b]						
Mean (SD) no of training sessions per week	1.30 (0.46)	1.40 (0.56)	0.033	1.29 (0.46)	1.40 (0.63)	n.s.
Mean (SD) no of matches per week	0.72 (0.30)	0.78 (0.38)	n.s.	0.72 (0.30)	0.84 (0.48)	n.s.
Mean (SD) match exposure ratio[c]	0.26 (0.10)	0.28 (0.17)	n.s.	0.26 (0.10)	0.28 (0.21)	n.s.
Match with other team, yes[d]	1169/4472 (26%)	24/92 (26%)	n.s.	1189/4543 (26%)	5/21 (24%)	n.s.
Artificial turf exposure, yes	2441/4472 (55%)	47/92 (51%)	n.s.	2476/4543 (55%)	12/21 (57%)	n.s.

ACL, anterior cruciate ligament; BMI, body mass index.

[a] P value from significance testing with ANOVA (continuous variables) or the Chi^2 test (categorical variables).

[b] Exposure data are reported up to first injury event (injured players) or during entire season (uninjured players).

[c] Match hours/total hours of exposure.

[d] Number of players who played matches with a district or national team or older youth/senior team within the club during study inclusion.

TABLE 3
Risk factors for acute knee injury based on Cox regression analysis

Analysis	Variable	Hazard Ratio	95% CI	P value
Step 1. Individual variable analysis[a]				
Intrinsic factors	Age > 14 years[b]	1.97	1.30-2.97	0.001
	Born first half of year, yes	1.21	0.80-1.83	n.s.
	BMI > 19.9 kg/m^{2}[b]	1.53	1.00-2.32	0.048
	Menarche, yes	2.19	1.19-4.02	0.012
	Previous acute knee injury, yes	2.47	1.44-4.23	0.001
	Current knee complaints, yes	1.98	1.30-3.02	0.001
	Familial disposition ACL injury, yes	1.96	1.22-3.16	0.005
Extrinsic factors	Training sessions per week > 1.30[b]	0.92	0.60-1.42	n.s.
	Matches per week > 0.72[b]	0.90	0.59-1.38	n.s.
	Match exposure ratio > 0.26[b,c]	0.93	0.61-1.39	n.s.
	Match with other team, yes	0.74	0.46-1.19	n.s.
	Artificial turf exposure, yes	0.74	0.49-1.12	0.150
Step 2. Multiple analysis[a,d]				
	Age > 14 years[b]	1.82	1.13-2.92	0.014
	BMI > 19.9 kg/m^{2}[b]	1.26	0.80-1.97	n.s.
	Menarche, yes	1.42	0.73-2.79	n.s.
	Previous acute knee injury, yes	1.68	0.94-3.00	n.s.
	Current knee complaints, yes	2.06	1.30-3.26	0.002
	Familial disposition ACL injury, yes	1.87	1.15-3.03	0.012
	Artificial turf exposure, yes	0.69	0.44-1.06	n.s.

BMI, body mass index; CI, confidence interval.
[a] All analyses adjusted for group belonging (intervention or control group)
[b] Variable dichotomised according to below or above cohort mean.
[c] Match hours/total hours of exposure.
[d] Variables with $P < 0.20$ in individual variable analysis were entered into multiple analysis.

TABLE 4
Risk factors for ACL injury based on Cox regression analysis

Analysis	Variable	Hazard Ratio	95% CI	*P* value
Step 1. Individual variable analysis[a]				
Intrinsic factors	Age > 14 years[b]	4.59	1.77-11.90	0.002
	Born first half of year, yes	2.60	1.08-6.27	0.034
	BMI > 19.9 kg/m^{2b}	2.40	0.96-6.00	0.063
	Menarche, yes	6.68	0.90-49.83	0.064
	Previous acute knee injury, yes	2.05	0.60-6.97	n.s.
	Current knee complaints, yes	1.02	0.37-2.79	n.s.
	Familial disposition ACL injury, yes	3.57	1.48-8.62	0.005
Extrinsic factors	Training sessions per week > 1.30[b]	0.75	0.29-1.93	n.s.
	Matches per week > 0.72[b]	0.92	0.37-2.26	n.s.
	Match exposure ratio > 0.26[b,c]	0.79	0.33-1.88	n.s.
	Match with other team, yes	0.61	0.22-1.72	n.s.
	Artificial turf exposure, yes	0.86	0.36-2.06	n.s.
Step 2. Multiple analysis[a,d]				
	Age > 14 years[b]	2.49	0.82-7.51	n.s.
	Born first half of year, yes	1.66	0.63-4.43	n.s.
	BMI > 19.9 kg/m^{2b}	1.56	0.61-3.99	n.s.
	Menarche, yes	3.11	0.37-26.45	n.s.
	Familial disposition ACL injury, yes	3.82	1.56-9.39	0.003

ACL, anterior cruciate ligament; BMI, body mass index; CI, confidence interval.
[a] All analyses adjusted for group belonging (intervention or control group).
[b] Variable dichotomised according to below or above cohort mean.
[c] Match hours/total hours of exposure.
[d] Variables with *P* < 0.20 in individual variable analysis were entered into multiple analysis.

TABLE 5

Sensitivity, specificity, positive and negative predictive values of variables to predict new acute knee injury or ACL injury.

	Acute knee injury (%)				ACL injury (%)			
	Sensitivity	Specificity	PPV	NPV	Sensitivity	Specificity	PPV	NPV
Age > 14 years	50	67	3	98	71	67	1	>99
BMI > 19.9 kg/m^2	55	56	3	98				
Menarche	87	26	3	99				
Previous acute knee injury	17	92	4	98				
Current knee complaints	38	76	3	98				
Familial disposition ACL injury	26	85	4	98	38	85	1	>99
Born first half of year					62	61	1	>99

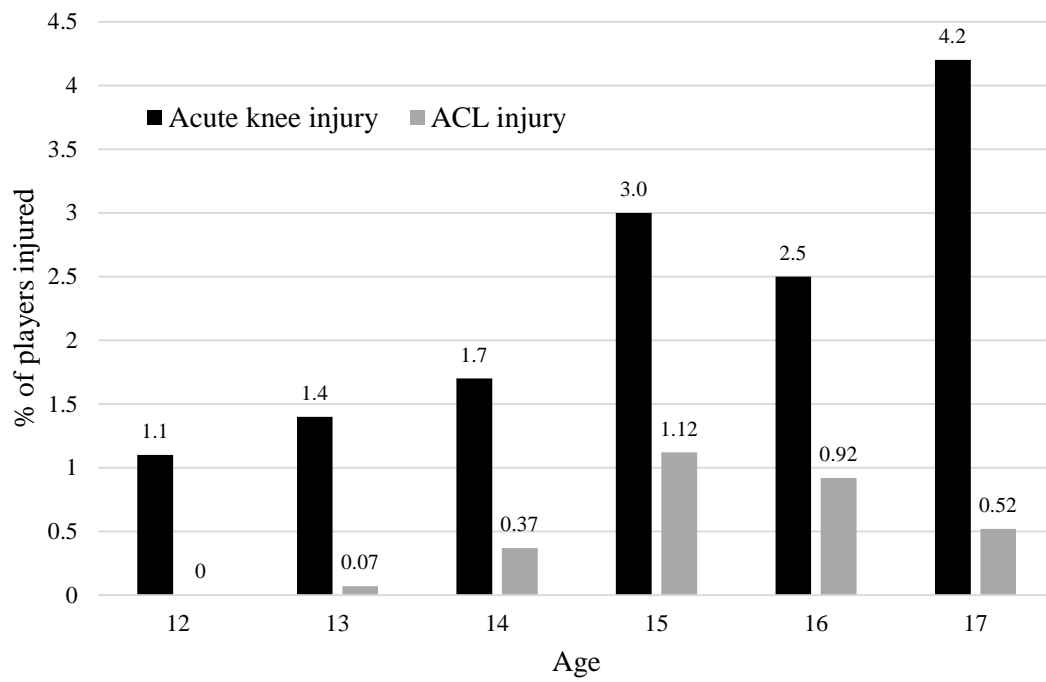ACL, Anterior cruciate ligament; BMI, Body mass index; PPV Positive predictive value; NPV Negative predictive value

FIGURE 1
Injury proportions by age group