Concomitant Injuries Associated With ACL Rupture in Elite Professional Alpine Ski Racers and Soccer Players

A Comparative Study With Propensity Score Matching Analysis

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Background: For elite professional soccer players and alpine skiers, injuries associated with anterior cruciate ligament (ACL) rupture, such as meniscal, cartilage, or collateral ligament lesions, could result in a delayed return to sport compared with isolated ACL injury.

Purpose/Hypothesis: The purpose of the study was to provide a detailed description of associated injuries at the time of primary ACL reconstruction in elite soccer players and alpine skiers. It was hypothesized that soccer players and skiers would present different typical injury patterns due to different injury mechanisms.

Study Design: Cohort study; Level of evidence, 3.

Methods: Surgical reports and arthroscopic images of elite professional soccer players and alpine skiers who underwent primary ACL reconstruction at a single institution between January 2010 and June 2022 were analyzed retrospectively. The presence and location of multiligamentous injury, meniscal tears, and chondral lesions were compared between the athlete groups. A propensity score matching analysis with 1:1 ratio was performed between skiers and soccer players to limit the effect of selection bias.

Results: Included were ACL reconstruction data representative of 37 soccer players and 44 alpine skiers. Meniscal pathology was found in 32 (86%) soccer players and 30 (68%) skiers. Chondral injuries were reported in 11 (30%) soccer players and 15 (34%) skiers. Results of the propensity score matching analysis in 15 pairs of soccer players and skiers indicated that soccer players had a significantly higher rate of medial meniscal injuries (73% vs 27%; $P = .03$) and lateral posterior root tears (33% vs 0%; $P = .04$) compared with skiers.

Conclusion: A higher prevalence of combined chondral and meniscal injuries versus isolated ACL injuries was observed in both groups of athletes. Professional soccer players were characterized by higher prevalence of medial meniscal tears and lateral posterior root lesions compared with professional alpine skiers.

Keywords: ACL rupture; alpine ski racers; cartilage; concomitant injuries; elite athletes; soccer; mechanism of injury; meniscus; posterior lateral root; ramp

Anterior cruciate ligament (ACL) rupture represents a serious injury for professional athletes.[8,12,19,23] Moreover, associated injuries, such as meniscal, cartilage, or collateral ligament lesions, may result in an increased risk of early osteoarthritis[2,7,20,26,28,30] and/or graft failure.[3,9,16,24,25,28,29] Because specific injury patterns are associated with certain sports, a better understanding of sport-specific injury mechanisms may lead to more personalized and effective ACL injury prevention programs.[31]

To the best of our knowledge, only a few studies have described the effect of sport-specific injury mechanisms on concomitant injuries during ACL rupture.[15,18,21,31] Granan et al[15] found that skiing is associated with increased odds of isolated ACL injuries and other ligament injuries but decreased odds of meniscal and cartilage injuries compared with soccer. Kluczynski et al[21] reported that male sex, high-impact sport (ie, soccer and skiing), and a history of instability episodes represent predictors of additional intra-

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articular injuries. Shi et al[31] analyzed the bone bruise patterns in the setting of ACL ruptures in basketball and soccer athletes. They reported no differences in terms of bone bruise patterns and type of meniscal injuries between sports. However, all of these studies reported the overall occurrence of meniscal and chondral injuries associated with ACL injuries without mention of location and type of lesion. Moreover, the subjects of these studies were not elite athletes, in whom the mechanisms of injury of ACL tears could be different from those seen at the recreational sport level.[34]

Previous studies have reported that alpine skiers and soccer players demonstrate different biomechanical patterns of injury.[5,15] The aim of the present study was to report a detailed description of associated injuries at the time of primary ACL reconstruction in elite athletes engaged in alpine ski and soccer. The hypothesis was that alpine skiers and soccer players would present with distinctive injury patterns due to different injury mechanisms.

METHODS

The protocol for this study received institutional review board approval, and all included participants provided written informed consent. The database of a specialized joint surgery clinic was screened for professional alpine skiers and elite professional soccer players who underwent primary ACL reconstruction between January 2010 and June 2022. To be included, athletes had to have participated in European and/or World Cup ski competitions or played in first-tier European soccer leagues according to the United European Football Association (UEFA) country ranking at the time of ACL injury. Athletes who had undergone primary ACL reconstruction elsewhere, as well as patients with missing surgical reports, were excluded. All included athletes were operated on by 1 of 2 experienced surgeons (C.F. and C.H.). ACL reconstructions involving interventions targeting meniscal or cartilaginous tissues or collateral ligaments were defined as complex ACL surgeries.

Participant demographics and anthropometric variables were retrieved from the clinic's own and/or publicly accessible databases, such as Transfermarkt (https://www.transfermarkt.com) and the International Ski and Snowboard Federation online database (https://www.fis-ski.com/DB/general/biographies.html). Concomitant injuries and associated treatments were extracted from the surgical reports and arthroscopic pictures by a sport knee surgery fellow (L.F.). A second fellow (A.M.) reviewed reports and pictures to verify the accuracy of the data. In case of discrepancies, the senior author (C.F.) was contacted for clarification.

Meniscal lesions were classified according to location (medial or lateral) and type as radial, bucket-handle, longitudinal, horizontal, and complex tears.[27] Peripheral lesions in the medial meniscocapsular zone, known as ramp lesions and root lesions, were classified independently.[11,13] The location of the chondral lesions was classified as lateral femoral condyle (LFC), medial femoral condyle (MFC), medial tibial plateau (MTP), lateral tibial plateau (LTP), and patellofemoral joint (PFJ). The International Cartilage Repair Society (ICRS) classification was used to classify the severity of chondral lesions: grade 1 (softening and fibrillation), grade 2 (defect involving $<50\%$ of cartilage thickness), grade 3 (defect involving $>50\%$ of cartilage thickness), or grade 4 (exposed subchondral bone).[35]

Statistical Analysis

All available data from professional ski racers and elite UEFA soccer player were included. Therefore, an a priori sample size calculation was not performed. Data were collected and organized with Excel (Microsoft, Version 16.75). Statistical analyses were performed using the XLSTAT statistical software (Addinsoft). All continuous variables are presented and expressed as means and standard deviations, and categorical data are expressed as numbers and percentages. The normal distribution of the measured variables was verified using the Shapiro-Wilk test.

We compared the distributions of variables through nonparametric tests because the variables were not normally distributed ($P < .001$). Specifically, Wilcoxon rank-sum tests for paired samples and Kruskal-Wallis tests for comparisons between more than 2 independent groups were used. The Fisher exact test was used to determine differences in categorical data between groups. The threshold for significance was set at $P = .05$.

Considering the retrospective nature of the study, a propensity score matching analysis with 1:1 ratio was performed to match the distributions of potentially biasing factors between the groups of alpine skiers and soccer players. The covariates included in the model were age, sex, height, weight, body mass index, and Tegner activity score. The matched variables were selected to control for potential

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TABLE 1
Demographic and Anthropometric Characteristics of the Study Participants[a]

	Soccer Players (n = 37)	Skiers (n = 44)
Age, y	23.7 ± 4.5	22.0 ± 3.7
Sex, female/male, n	2/35	24/20
Height, cm	182.6 ± 6.3	174 ± 0.9
Weight, kg	77.4 ± 7.1	72.9 ± 11.0
BMI, kg/m^2	23.2 ± 1.5	24.0 ± 2.0
Injury mechanism, n (%)		
Contact	6 (16)	—
Noncontact	31 (84)	—
Landing back weighted[b]	—	10 (23)
Dynamic snowplow or slip-catch[c]	—	34 (77)
Side of ACL injury, n (%)		
Right	25 (68)	23 (52)
Left	12 (32)	21 (48)

[a]Data are expressed as mean ± SD unless otherwise indicated. Dashes indicate areas not applicable. ACL, anterior cruciate ligament; BMI, body mass index.
[b]Anterior tibial translation plus valgus-internal rotation mechanism.
[c]Valgus internal rotation mechanism.

TABLE 2
Spectrum of Concomitant Meniscal Lesions in the Study Participants[a]

	Soccer Players (n = 37)	Skiers (n = 44)	P
Medial meniscal lesions	21 (57)[b]	17 (39)[c]	ns
Ramp	5 (14)	2 (5)	ns
Bucket handle	4 (11)	7 (16)	ns
Isolated radial tear	4 (11)	0 (0)	.04
Longitudinal	7 (19)	6 (14)	ns
Complex tear	1 (3)	2 (5)	ns
Lateral meniscal lesions	24 (65)[d]	25 (57)[e]	ns
Root	6 (16)	0 (0)	.01
Bucket handle	1 (3)	1 (2)	ns
Radial tear	6 (16)	5 (11)	ns
Longitudinal	9 (24)	12 (27)	ns
Complex tear	2 (5)	7 (16)	ns

[a]Data are expressed as n (%). Radial, longitudinal, and complex tears were all located in the body-posterior horn of the meniscus. ns, not significant.
[b]13 athletes had additional lateral meniscal injuries.
[c]12 athletes had additional lateral meniscal injuries.
[d]13 athletes had additional medial meniscal injuries
[e]12 athletes had additional medial meniscal injuries.

confounders having an influence on the type of associated injuries of ACL rupture. A predefined caliper width of 0.1 with 95% confidence interval (CI) and 0.001 tolerance was used. This resulted in 15 pairs of professional elite skiers and soccer players. Post hoc power analysis was performed to assess the power of the study.

RESULTS

During the observation period, 37 elite soccer players and 33 professional alpine skiers who underwent primary ACL reconstruction in our clinic were included in the study. Of the 33 skiers, 11 (33%) sustained bilateral ACL tears; therefore, the total number of knees with primary ACL tears in the skier group considered for analysis was 44. The post hoc power analysis revealed an actual power of 73% and 78% for detecting differences between the study groups regarding medial meniscus and lateral meniscus root injuries, respectively (G*Power 3.1). The demographic and anthropometric characteristics of the alpine skiers and soccer players are summarized in Table 1.

The types of meniscal injuries are reported in Table 2. Radial, longitudinal, and complex tears were all located in the body-posterior horn of the meniscus. Both groups were characterized by a higher rate of lateral meniscal tears compared to medial injuries. In soccer players, ramp lesions and longitudinal tears represented 14% and 19%, respectively, of all injuries on the medial side. On the lateral side, longitudinal tears and radial tears represented 24% and 16% of all injuries, respectively. Posterior root lesions represented 16% of injuries. In alpine skiers, the most common types of medial meniscal tears were bucket handle and longitudinal tears. On the lateral side, longitudinal and complex tears represented 27% and 16% of all tears, respectively. The number of radial tears of the medial meniscus and posterior lateral root avulsions differed significantly between groups ($P = .04$ and .01, respectively).

Table 3 summarizes the ACL reconstruction procedure and concomitant injuries and procedures. In soccer players, 11 athletes (30%) had chondral injuries of ICRS grade 3 or 4; most of them with MFC lesions or LFC lesions. Two patients had medial collateral ligament injuries, of whom 1 required reconstruction. In skiers, 15 athletes (34%) had chondral injuries of ICRS grade 3 or 4; most of them had MFC lesions or LFC lesions. Five patients had medial collateral ligament injuries, of whom 2 required reconstructions.

The results of the propensity score matching analysis in 15 pairs of elite alpine skiers and soccer players are shown in Table 4. There were no significant differences in terms of age, sex, weight, height, body mass index, or Tegner activity score after matching. Regarding the comparison of associated injuries, medial meniscal injuries and posterior lateral root tears were more common in soccer players as compared with alpine skiers ($P = .03$ and .04, respectively).

DISCUSSION

The most important finding of the present study was that ACL tears were accompanied by different concomitant injuries in alpine ski racers and elite soccer players, with medial meniscal and posterior lateral meniscal root injuries being observed more frequently in soccer players. The different injury patterns may be related to different mechanisms of trauma according to sport.[33]

TABLE 3
Breakdown of Injuries and Procedures[a]

	Soccer Players (n = 37)	Skiers (n = 44)	*P*
Isolated/complex ACL surgery[b]	7 (19)/30 (81)	11 (33)/33 (67)	ns
Graft type			
HT	0 (0)	26 (59)	<.01
BPTB	21 (57)	0 ()	<.01
QT	16 (43)	18 (41)	ns
Concomitant procedures or injuries			
Meniscectomy			
Medial	6 (16)	4 (9)	ns
Lateral	6 (16)	9 (20)	ns
Meniscal repair			
Medial	15 (41)	13 (30)	ns
Lateral	18 (49)	16 (36)	ns
Cartilage lesions			
PFJ	4 (11)	4 (9)	ns
MFC/LFC	8 (22)	9 (20)	ns
MTP/LTP	1 (3)	4 (9)	ns
Chondroplasty	8 (22)	5 (11)	ns
Nanofracture	1 (3)	0 (0)	ns
MCL injury	2 (5)	5 (11)	ns
Nonoperative treatment	1 (3)	3 (7)	ns
Repair/reconstruction	1 (3)	2 (5)	ns

[a]Data are expressed as n (%).BPTB, bone-patellar tendon-bone; HT, hamstring tendon; LFC, lateral femoral condyle; LTP, lateral tibial plateau; MCL, medial collateral ligament; MFC, medial femoral condyle; MTP, medial tibial plateau; ns, not significant; PFJ, patellofemoral joint; QT, quadriceps tendon.

[b]ACL reconstruction involving interventions targeting meniscal or cartilaginous tissues or collateral ligaments were defined as complex ACL surgery.

TABLE 4
Results of Propensity Score Matching Analysis of Concomitant Meniscal Lesions[a]

	Soccer Players (n = 15)	Skiers (n = 15)	*P*
Sex, female/male, n	2/13	2/13	ns
Age, y	22.9 ± 3.8	22.7 ± 3.0	ns
Height, cm	179.1 ± 6.4	179.9 ± 4.9	ns
Weight, kg	77.8 ± 8.5	79.8 ± 8.5	ns
BMI, kg/m^2	24.2 ± 1.4	24.6 ± 1.6	ns
Medial meniscal lesions	11 (73)	4 (27)	.03*
Ramp	4 (27)	1 (7)	ns
Bucket handle	1 (7)	0 (0)	ns
Isolated radial tear	2 (13)	0 (0)	ns
Longitudinal	3 (20)	2 (13)	ns
Complex tear	1 (7)	1 (7)	ns
Lateral meniscal lesions	11 (73)	8 (53)	ns
Root	5 (33)	0 (0)	.04*
Bucket handle	0 (0)	0 (0)	ns
Radial tear	1 (7)	4 (27)	ns
Longitudinal	4 (27)	2 (13)	ns
Complex tear	1 (7)	2 (13)	ns

[a]Data are expressed as mean ± SD or n (%) unless otherwise indicated. BMI, body mass index; ns, not significant.

*Fisher exact test (1-tailed).

Recently, several studies analyzed the mechanisms of ACL injury in professional ski racers.[4-6] Bere et al[6] reviewed 20 cases of ACL injuries in professional alpine skiers and described 3 distinctive mechanisms: the slip-catch, landing back-weighted, and dynamic snowplow. All 3 mechanisms are associated with excessive internal rotation and valgus loading of the knee. Moreover, when landing in a back-weighted position, eccentric quadriceps contraction combined with knee flexor muscle relaxation and knee hyperflexion could act as "anterior drawer" stress and lead to ACL injury.[1] By contrast, video analyses have demonstrated that external rotation and anterior translation of the tibia with valgus stress of the knee represents the main mechanism for ACL injury in professional soccer players.[10,11,22,31]

Injuries to the lateral meniscal root were found to be significantly ($P < .05$) more common in soccer players compared with ski racers (16% vs 0% before matching and 33% vs 0% after matching). To date, scant information exists to explain the underlying mechanisms. Moreover, no previous studies described the prevalence of posterior lateral meniscal root tears in professional alpine skiers. From biomechanical studies, it is known that the posterior lateral root represents a secondary stabilizer countering anterior tibial translation.[13,14] Also, injuries of the lateral posterior root significantly increase anterior tibial translation and pivot shift in ACL-deficient knees.[13,14] Therefore, it is plausible to assume that forceful anterior translations may represent the main risk factor for root tears. A possible explanation of our results was that only 23% of ACL injuries to alpine skiers were due to a back-weighted landing, ie, a situation where the knee is stressed due to a forceful anterior tibial translation.[4,5,32] In contrast, the main mechanism of external rotation and anterior translation of the tibia with valgus stress of the knee in soccer players could explain the higher incidence of lateral meniscal root tear compared with skiers.

Our results indicated that the prevalence of medial meniscal injuries was higher in soccer players than skiers after propensity score matching ($P = .03$). Studies with computational knee models could explain this finding. It has previously been reported that anterior tibial translation and external tibial rotation (ie, the typical injury mechanisms in soccer players) increase the compressive forces on the posterior horn of the medial meniscus due to the contact of the meniscus with the MFC.[17] However, additional studies are necessary to confirm these results.

Limitations

The current study has limitations. Small sample sizes are an inherent problem when elite athlete populations are studied. However, the post hoc analysis revealed a power of 73% and 78%. Most athletes included after matching were male; therefore, sex-specific differences in injury

patterns cannot be ruled out in general population. Lastly, we did not analyze respectively the differences of pitch position (ie, goalkeeper, defender, midfield, forward) and preferred discipline (downhill, slalom, super G) in soccer and alpine skiing. However, the present study provides current and unique data on the type of concomitant injuries during ACL tears in alpine ski racers and soccer players despite the bias reported above. All reconstructions were performed in a single clinic by 1 of 2 experienced surgeons; therefore, no bias related to surgical reports or surgical procedures is present.

CONCLUSION

A higher prevalence of combined chondral and meniscal injuries versus isolated ACL injuries was observed in both alpine ski racers and elite soccer players. The latter group was characterized by a higher prevalence of medial meniscal injuries and lateral posterior meniscal root lesions. Additional studies are required to verify these data.

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