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original research

Rate and Risk of Anterior Cruciate Ligament Injury Among Sportswomen in Slovenia

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Context: Anterior cruciate ligament (ACL)-injury rate is greater among female athletes than among male athletes.

Objective: To investigate the rate and risk of ACL injury among Slovenian sportswomen playing professional basketball, team handball, or volleyball.

Design: Prospective cohort study.

Setting: The Slovenian National Organizations of basketball, team handball, and volleyball.

Patients or Other Participants: During the 2003–2004 season, we prospectively followed 585 Slovenian sportswomen registered in the Slovenian National Organizations of basketball, team handball, and volleyball.

Main Outcome Measure(s): We asked sportswomen and coaches to document the occurrence of every significant traumatic knee injury requiring medical attention. Injury rate and injury risk were calculated for sportswomen in each sport group. To calculate injury rate, we estimated the average exposure of each sportswoman during the research period.

Results: During the 2003–2004 season, 585 Slovenian sportswomen sustained 12 ACL injuries. The ACL-injury risk was different in athletes participating in the various sports, with basketball players having the greatest ACL-injury risk and volleyball players having the lowest ACL-injury risk ($P = .04$). The risk of ACL injury among Slovenian sportswomen was 2.1 per 100 athletes (95% confidence interval = 0.9, 3.2), whereas the rate of ACL injury was 0.037 per 1000 exposure hours (95% confidence interval = 0.016, 0.06).

Conclusions: Overall differences in injury risk were found among sports, but no differences were noted among divisions within sports. No differences for injury rate were observed between or within sports. The rate and risk of ACL injury among Slovenian sportswomen are high, with basketball players having the greatest ACL-injury risk.

Key Words: female athletes, cohort study, injury epidemiology, traumatic injuries

Key Points

- Differences in anterior cruciate ligament injury risk were seen among female Slovenian basketball, team handball, and volleyball players. Basketball players were at greatest risk and volleyball players at lowest risk.
- No differences in injury rate were noted among athletes in the 3 sports or among athletes in different divisions of the same sport.

To implement successful injury-prevention strategies, it is important to target limited resources at the groups that are most likely to incur injury. Traumatic knee injury risk is greater in female athletes than in male athletes.[1] In particular, the injury rates are greater in female basketball,[2] soccer,[3] team handball,[4] and volleyball players than in their male counterparts.

Most of the researchers addressing knee-injury epidemiology have investigated either anterior cruciate ligament (ACL)-injury rates and risks or overall knee-injury rates and risks, including traumatic and overuse knee injuries. The definitions of the types of knee injuries vary among studies. To date, the rate and risk of ACL injuries in volleyball, basketball, and team handball have not been compared within a single study, which is likely due to the physical similarities of these sports. Stresses on the knee are likely to be comparable in these sports because the physical activities are similar (jumping, pivoting, etc). Despite these commonalities, suspected similarities in injury risk need to be identified because subtle anatomical differences may exist among the females participating in each sport or the demands of the sport themselves may be different.

A number of authors[5–9] have compared knee-injury rates and risks in different divisions or different levels of play of individual sports and reported various results. Emerson[7] reported that professional basketball players sustained ACL injuries less frequently than players at other levels and argued that this was the result of a "natural selection process of ACL integrity." Several other groups[6,9–11] reported disparities in injury rates among athletes in different divisions. In their retrospective study, Bjordal et al[6] found that male soccer players in the top 3 Norwegian

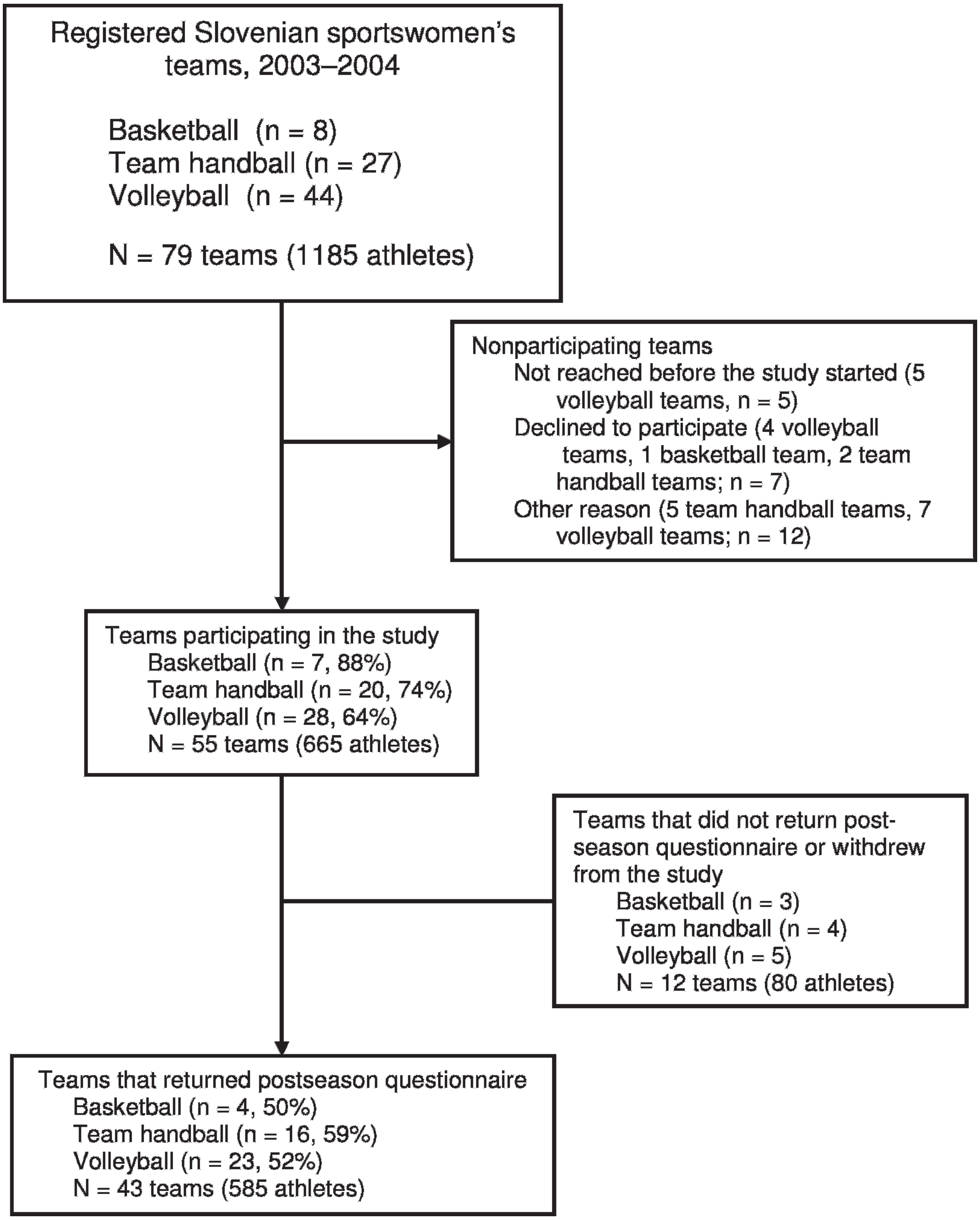

Figure. Data collection flow chart.

soccer divisions had higher ACL-injury rates than did male soccer players in other divisions. Shankar et al[9] looked at injury rates for all parts of the body between US high school and university football players and noted greater injury rates for the latter in both practice and competition (8.61 versus 4.36 per 1000 athlete-exposures). Several other authors[10,11] who compared injury rates between US high school and middle school–aged football players reported this trend of greater injury rates as the level of competition (eg, age, division) increased. In contrast, Harmon and Dick[8] reported no difference in ACL-injury rates among players at different divisions in basketball and soccer. To develop effective injury-prevention programs, it is important to not only recognize the possible differences in injury rates among athletes in different divisions but also to investigate differences among divisions in different sports.

In organized sports in Slovenia, females play volleyball in 3 divisions, team handball in 2 divisions, and basketball in 1 division. Our first hypothesis was that the risk of ACL injury would differ among these 3 sports in female Slovenian participants. The second hypothesis was that the risk of ACL injury would differ among sportswomen in different divisions, with those in the higher divisions having greater ACL-injury risks than those in the lower divisions.

METHODS

Using a cohort study design, we prospectively followed Slovenian sportswomen playing basketball, team handball, or volleyball during the 2003–2004 season. The data-collection flowchart appears in the Figure. In Slovenian team sports such as basketball, volleyball, and team handball, both the teams and their players need to be registered with the Slovenian National Sport Organisation in order to compete in the Slovenian National Sport league, which is classified as a professional league. In total, 79 teams (1185 female athletes) were registered for the 2003–2004 season. A total of 55 teams entered the study; the rest did not participate because they either could not be contacted or declined. All athletes competing for the participating teams who had no recent history (in the last 6 months) of any knee or lower leg injury that required medical attention were included in the study (N = 665).

All sportswomen signed an informed consent form. At the beginning of the season, each athlete completed a preseason questionnaire regarding average training and game hours per week. We referred to these data as the *preseason testing data*; analysis of these data has been published.[12,13] At the same time, information for the following variables was collected: age, height, mass, age at menarche, use of oral contraception, regularity of menstrual cycle, duration of sport participation, training and game exposure per week, leg dominance, knee-extension passive range of motion, navicular drop, and knee anterior laxity at 3 different forces (15 lb [6.8 kg], 20 lb [9.1 kg], and 30 lb [13.7 kg]).

Twelve teams were excluded from the analysis because they either did not complete the postseason questionnaire (2 basketball, 4 team handball, and 5 volleyball teams) or withdrew from the study (1 basketball team; no reason stated). The study was thus completed by 43 clubs and 585 athletes (49% of the target population). Given that all the exclusions occurred at the club level, we can assume that they are independent of the actual injury risk and, therefore, our sample is still representative of the population. To test this assumption, we looked at the differences in all available variables between the excluded and nonexcluded sportswomen. Despite the large samples (585 nonexcluded, 80 excluded), only height and average game hours per week were different ($P = .025$ and $P = .011$, respectively); in both cases, the differences were small enough (2 cm and 0.3 hours, respectively) that we determined they were not clinically relevant.

Injury Definition

We asked sportswomen and coaches to report every traumatic knee injury to the first author (R.V.). To ensure the accurate reporting of traumatic knee injuries, we offered the teams immediate medical care (within 48 hours) by our study-team surgeon for every knee injury. Injured athletes were asked to fill in the injury-registration form. The surgeon examined the injured sportswoman in the first 48 hours after initial injury, obtained magnetic resonance imaging (MRI), and performed arthroscopy to determine whether an ACL injury had occurred. At the end of the season, we also asked coaches at the sport clubs to fill in the postseason questionnaire regarding athletes whose injuries were not reported to us at the time of injury and not evaluated by our study-team surgeon during the season. We requested medical notes with MRI or arthroscopy results in order to determine whether the ACL had been injured. All ACL injuries were diagnosed by either MRI or arthroscopy. These techniques were used because they are accurate in ACL-injury diagnosis.[14] In addition, because we used ACL injury data from the postseason questionnaire, it was important that the techniques for ACL-injury diagnosis be reliable and valid. Eight ACL injuries were diagnosed by the study-team surgeon, and 4 ACL injuries were diagnosed by nonteam surgeons.

Calculation of Exposure, Injury Rate, and Injury Risk

As suggested by Knowles et al,[15] *injury risk* was defined as the number of injured sportswomen divided by the number of sportswomen who participated in the sport, multiplied by 100. This gave a rough estimate of the likelihood that a sportswoman would sustain an ACL injury during a sport season. *Injury rate* was determined by dividing the number of injuries by the total number of hours the sportswomen participated in games and training sessions during 1 season and defined per 1000 hours of exposure. In the present study, we calculated exposure for each sportswoman using her date of preseason testing (starting point of observation), date of the end of data collection (ie, the last observation: end of season for the uninjured group, dates of ACL injuries for the injured group), and her data regarding average hours of training and games per week. Training and game hours per week were summed and used for the analysis.

Analyses

We compared means of the baseline demographic variables among sport groups using 1-way analysis of variance. When differences among sport groups were noted, a post hoc Duncan test was performed to investigate these differences. The rate and risk of ACL injury was calculated for participants in basketball, team handball, and volleyball overall and separately for each sport and each division within the sport. The Fisher exact test was used to identify if the sportswomen playing in the various divisions and sports had different risks of ACL injury. To allow for several injuries per individual and to take into account the hours of exposure, we assessed the differences in injury rates with a generalized linear model (Poisson model). The significance level for all tests was set at $P < .05$. In addition, risk ratios and rate ratios (including 95% confidence intervals) were calculated to provide a measure of the magnitude of the differences among sports and divisions. The analysis was performed using the statistical package SPSS (version 17 for Windows; SPSS Inc, Chicago, IL).

RESULTS

Differences were noted for the following variables: age, height, mass, body mass index, duration of sport participation, and average hours of training and games per week ($P < .05$; Table 1). Basketball players were older than team handball players and taller and heavier than team handball and volleyball players. Volleyball players had lower body mass indexes than basketball and team handball players. In terms of sport participation, basketball players remained active in sport longer than volleyball players and had more training exposure hours than volleyball and team handball players. Volleyball players had fewer game exposure hours than basketball and team handball players.

Table 1. Demographic Variables of Study Participants

Variable	Sport						All Participants (n = 585)	
	Basketball (n = 41)		Team Handball (n = 258)		Volleyball (n = 286)			
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Age, y[a]	20.2 ± 3.9	15–32	17.7 ± 3.7	11–41	18.1 ± 3.3	12–38	18.1 ± 3.6	11–41
Height, cm[b]	176 ± 6	168–192	170 ± 6	147–188	173 ± 6	158–189	172 ± 6	147–192
Mass, kg[c]	67 ± 8	54–101	64 ± 8	40–90	63 ± 8	45–105	63 ± 8	40–105
Body mass index, kg/m^2[d]	19.0 ± 1.7	15.9–26.3	18.7 ± 2.1	13–27.1	18.1 ± 1.9	13.2–28.8	18.4 ± 2.0	13.0–28.8
Duration of sport participation, y[e]	9 ± 3.6	3–18	7.7 ± 3.8	1–30	6.9 ± 3.1	1–23	7.4 ± 3.6	1–30
Average training exposure per week, h[f]	12 ± 3	2–15.0	7 ± 2	2–17.0	7 ± 3	2–20.0	8 ± 3	2.0–20.0
Average game exposure per week, h[g]	2 ± 1	1–5.0	1 ± 1	1–4.0	2 ± 1	1–8.0	2 ± 1	1.0–8.0

[a] Difference between basketball and team handball: $P = .013$.
[b] Difference between (1) basketball and (2) team handball and volleyball: $P < .001$.
[c] Difference between (1) basketball and (2) team handball and volleyball: $P = .001$.
[d] Difference between (1) basketball and (2) team handball and volleyball: $P = .001$.
[e] Difference between basketball and volleyball: $P = .017$.
[f] Difference between (1) basketball and (2) team handball and volleyball: $P = .001$.
[g] Difference between (1) basketball and volleyball and (2) team handball: $P = .001$.

During the season, 12 sportswomen injured their ACLs. Two sportswomen had isolated ACL injuries, and 10 had ACL injuries with medial collateral ligament injury, medial meniscus injury, or cartilage damage (or a combination of these). Rate and risk calculations for ACL injuries are presented in Table 2. Different sports were associated with different ACL-injury risks ($P = .04$), with basketball players having the highest risk and volleyball players having the lowest risk. Rate trends are similar, although less pronounced ($P = .16$). Because basketball in Slovenia is played in 1 division, team handball in 2 divisions, and volleyball in 3 divisions, we also compared the ACL-injury risk among sportswomen playing basketball, team handball, or volleyball in the first divisions and found no difference ($P = .56$).

The risk of ACL injury did not differ among volleyball players playing in different divisions ($P = .16$; Table 3) or among team handball players playing in different divisions ($P = .06$). The magnitude of the differences between sports is further presented in Table 4: the estimated risk ratio between basketball and volleyball is almost 7, whereas the ratio between basketball and handball is 3.14. The rate ratios follow the same trend but are less pronounced.

DISCUSSION

In this sample, basketball players were at higher risk for ACL injury than were volleyball and team handball players (Table 2). The risks and rates we report have large confidence intervals and, therefore, only the overall difference in ACL-injury risk among the sports is statistically significant. Strictly speaking, the first hypothesis—of a difference (at the .05 significance level) in ACL-injury risk—can be accepted. Nevertheless, because this result is only barely significant and the sample size is small, we believe that this matter should be further investigated, especially given that the differences in our sample were surprisingly large (the injury risk ratio between basketball and volleyball was as high as 7). More injuries in the first division than in the second were observed in both handball and volleyball players (Table 3), but the differences were not significant, most likely because of the small sample size. The second hypothesis of difference in ACL-injury risk among divisions cannot be rejected; nevertheless, the confidence intervals indicate that the differences might be substantial but cannot be detected because of the low number of cases (with respect to the rarity of the events) included in the analysis.

Differences were noted between women in different sports in terms of age, height, mass, body mass index, duration of sport participation, and average hours of training and games per week. Some of these differences (eg, height, mass, body mass index) can be attributed to the sport in general, whereas some (eg, duration of sport participation, exposure) might be unique to Slovenian sportswomen.

Closer comparison with studies in the literature is rather difficult because most of the authors report overall knee-injury risk,[16,17] with 2 groups[2,18] separating data into overuse and traumatic knee injuries, one group[19] separating data into ACL and non-ACL injuries, and one group[20] providing only cruciate ligament injury rates and risks. In

Table 2. Anterior Cruciate Ligament (ACL)-Injury Rates and Injury Risks for Slovenian Sportswomen Overall and by Sport

Group	ACL Injuries, No.	Exposure, h	Injury Rate (95% Confidence Interval)[a]	Injury Risk (95% Confidence Interval)[b]
All participants (N = 585)	12	320 290	0.037 (0.016, 0.06)	2.1 (0.9, 3.2)
Sport				
Basketball (n = 41)	3	33 408	0.090 (0, 0.19)	7.3 (0, 15)
Team handball (n = 258)	6	127 673	0.047 (0.009, 0.09)	2.3 (0.5, 4.2)
Volleyball (n = 286)	3	159 209	0.019 (0, 0.04)	1.0 (0, 2.9)

[a] Injury rate was calculated using the number of sportswomen with ACL injuries divided by hours of exposure and multiplied by 1000.
[b] Injury risk was calculated using the number of sportswomen with ACL injuries as the numerator and the number of sportswomen in a particular sport as the denominator, multiplied by 100. Differences were noted among all sports: $P = .04$.

Table 3. Anterior Cruciate Ligament (ACL)-Injury Rates and Injury Risks for Slovenian Team Handball and Volleyball Sportswomen by Division

Sport	Division	ACL Injuries, No.	Exposure, h	Injury Rate (95% Confidence Interval)[a]	Injury Risk (95% Confidence Interval)[b]
Team handball	1 (n = 117)	5	61 752	0.08 (0.01, 0.015)	4.3 (0.6, 7.9)
	2 (n = 141)	1	65 290	0.02 (0, 0.04)	0.7 (0, 2.1)
	P value			.13	.06
Volleyball[c]	1 (n = 67)	2	49 037	0.04 (0, 0.10)	3.0 (0, 7.0)
	2 (n = 121)	1	70 145	0.01 (0, 0.04)	0.8 (0, 2.4)
	P value			.39	.16

[a] Injury rate was calculated using the number of sportswomen with ACL injuries divided by hours of exposure and multiplied by 1000.
[b] Injury risk was calculated using the number of sportswomen with ACL injuries as the numerator and the number of sportswomen in a particular sport as the denominator, multiplied by 100.
[c] Volleyball was played in 3 divisions, but no ACL injuries occurred in Division 3.

addition to the different types of injuries studied, injury-rate and injury-risk calculations were diverse, with different variables used in the formulas. The investigators also followed sportswomen during different periods of time (ranging from 1 to 16 seasons) and at different competition levels (ranging from the 1st division to the 3rd division). We investigated only ACL injuries among sportswomen in Slovenia during a single season.

The rate of ACL injuries for basketball players in our study is the same (0.09) as that reported by Messina et al.[19] When the rate of ACL injuries between these studies is compared, the following points need to be made. The formulas for the injury-rate calculation used in these studies were very similar, with only slightly different calculations of exposure. Messina et al[19] used average training and game time per team per week, whereas we used average training and game time per week for each sportswoman. Messina et al[19] assumed that all sportswomen would have the same training and game exposures. However, basketball in particular is a sport in which players enter and leave games and training sessions; therefore, all basketball players are less likely to have the same exposure, indicating that the injury rate calculated by Messina et al[19] might be underestimated. On the other hand, our injury-rate calculation accounted for differences in exposure among sportswomen because we calculated exposure for each sportswoman individually. Therefore, the injury rate in our study is likely a more accurate estimate of ACL-injury rate.

We found only 1 study[20] of ACL-injury rates and risks among team handball players that can be compared with our data. The ACL-injury risk in our study (2.3) was similar to that reported by Myklebust et al,[20] but they provided cruciate ligament injury risks of 1.3, 2.0, and 4.5 for divisions 3, 2, and 1, respectively. They did not indicate if the differences among the divisions were significant. The difference in ACL-injury risks between the first and second team handball divisions in our study was not significant (*P* = .06), although the observed difference (injury risk ratio = 6.1) was large. The wide confidence intervals indicate that clinically important differences in ACL-injury risk between the first and second team handball divisions may not have been statistically significant because of the small sample size. Myklebust et al[20] included both ACL (n = 54) and posterior cruciate ligament (n = 5) injuries; from the data published in their article, it is not possible to calculate specific ACL-injury risks. In addition to the fact that they calculated injury rate for cruciate ligament injuries overall, another reason for differences between these studies may lie in their exposure calculation: they used only game exposure, whereas we used the sum of game- and training-exposure data. Because the injury rate is greater during games than during training,[4,21–23] it is not surprising that Myklebust et al[20] found a higher injury rate.

The only possible comparable study in volleyball players is that of Agel et al.[17] They reviewed 16 years of National Collegiate Athletic Association injury-surveillance data for women's volleyball and reported that of the knee internal-derangement injuries, 26.3% were ACL injuries. The injury rate for all knee internal-derangement injuries was 0.46 and, using their data regarding percentage of ACL injuries, the calculated ACL-injury rate was 0.12, which is much higher than the injury rate we report (0.02). Differences in the results between Agel et al[16] and the present study primarily reflect the fact that Agel et al[17] studied collegiate women volleyball players, whereas we studied volleyball players playing in the Slovenian National League. In addition, Agel et al[17] reported 16 years of follow-up; we reported only 1 year of follow-up, which likely resulted in fewer injuries being "captured."

Injury-prevention research is identified as a 4-step research process.[24] The first step is to determine the magnitude of the injury problem and to describe it in terms of the incidence. Once injury rates and risks are known, the second step is to identify risk factors and injury mechanisms. The third step is to introduce measures that are likely to reduce the future risk or severity (or both) of injuries. The final, fourth step is to evaluate the effect of preventive measures by repeating the

Table 4. Anterior Cruciate Ligament Injury Risk Ratios and Rate Ratios in Slovenian Basketball, Team Handball, or Volleyball Sportswomen

Comparison	All-Divisions Risk Ratio (95% Confidence Interval)	All-Divisions Rate Ratio (95% Confidence Interval)	Division 1 Risk Ratio (95% Confidence Interval)
Basketball (n = 41): team handball (n = 258)	3.14 (0.82, 12.1)	1.91 (0.48, 7.64)	1.71 (0.43, 6.85)
Basketball (n = 41): volleyball (n = 286)	6.98 (1.82, 26.8)	4.77 (0.96, 23.6)	2.45 (0.43, 14.1)
Team handball (n = 258): volleyball (n = 286)	2.22 (0.58, 8.52)	2.49 (0.62, 9.97)	1.43 (0.29, 7.18)

first step, which can be achieved with either time-trend analysis of injury patterns or randomized clinical trials. This is the first study to investigate ACL-injury rates and risks among Slovenian sportswomen playing basketball, team handball, or volleyball. Sportswomen playing basketball were at greater risk for ACL injury than were sportswomen playing team handball or volleyball. Future researchers should investigate why these differences in injury risk among sports are occurring and whether they are related to training programs in each sport. In addition, when injury-prevention programs are developed, specific attention should be given to sportswomen playing basketball, who are at greater risk than female athletes in other sports. Traumatic knee injuries, particularly ACL injuries, are among the more seriously disabling injuries in sport, with prevalent short-term and long-term disabilities.[1] They can limit both game and practice time and performance level. Many ACL injuries are season ending or career ending and can lead to secondary knee disorders, such as osteoarthritis,[1] which can reduce independence and affect quality of life.[1] Therefore, clinicians and researchers in the field of sports medicine must further determine the risk factors for ACL injury and, with their increased knowledge of risk factors, develop more effective and appropriate prevention strategies.

Study Limitations

Several limitations need to be considered when interpreting the ACL-injury rates and risks for these Slovenian professional sportswomen. When injury rates are calculated, exposure recording is a very important issue. In our study, ideally daily records of game and training exposure from each of the sportswomen studied would have been collected. However, the exposure was calculated based on the self-reported planned average participation during the season, which might affect the results. It is also possible that a percentage of athletes left their teams during the season, overestimating the overall exposure. Nevertheless, the data were collected in the same manner for all teams and sports and, therefore, the potential bias and level of uncertainty can be assumed to be comparable among the sports and divisions. Hence, the reported exposure hours and injury rates can be regarded only as a very crude estimate of the actual quantities but can nevertheless be used as a conservative-estimate weighting factor when comparing the different sports and divisions.

Other limitations of this study are that the injury-registration period was limited to 1 competitive season, and not all sportswomen were tested at the same time at the start of the season. Testing was performed from August 2003 to December 2003; the season for all clubs started in August (including the preseason training period) and lasted until June. In addition, because we relied on the participants' memories to identify previous knee and lower leg injuries in the preseason questionnaire and because only knee and lower leg injuries that required medical attention were recorded, recall bias might have occurred.

By providing the teams with a study instruction protocol, we assumed that the reliability of data recording would improve. Ideally, a study-team member would attend all of the game and training sessions to record traumatic knee injuries, but this was not possible. Therefore, some ACL injuries might have been missed, which would decrease the rate and risk results. This concern led us to develop and distribute a postseason questionnaire. The questionnaire helped the research team to identify ACL injuries that were not reported at the time of injury (n = 4, one-third of all the detected ACL injuries). Even though participating sport clubs were offered immediate medical care within 48 hours by our team surgeon, which is an extremely advantageous situation in Slovenia, not all coaches took advantage of this opportunity. Not only was the quality of our results affected, but Slovenian coaches' ignorance about possible career-ending injuries was apparent.

The main limitation of our study is the low sample size with respect to the rarity of events. As a result, all the injury-risk and injury-rate estimates have large confidence intervals. For example, only extremely pronounced differences among sports were significant, whereas some clinically important differences in ACL-injury risk might not have reached the threshold for statistical significance, especially when considering the risks within divisions. It is therefore crucial to take this degree of uncertainty into account when interpreting the results.

CONCLUSIONS

The risk of ACL injuries among Slovenian sportswomen playing basketball, team handball, or volleyball was different, with sportswomen playing basketball at greatest risk. Injury-prevention programs for the ACL should focus on these sports, especially basketball. We found no difference in ACL-injury risk among divisions within sports, even though the observed risks and rates were less in the lower divisions. The limitations and problems encountered in this study should be considered when future researchers design related studies.

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