Interaction of Potential Intrinsic and Extrinsic Risk Factors in ACL Injured Recreational Female Skiers

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Key words
- anterior cruciate ligament (ACL)
- risk factor
- multifactorial injury causation
- alpine skiing

Abstract

The aim of this study was to investigate the interaction of potential intrinsic and extrinsic risk factors in ACL injured recreational female skiers. 93 female recreational skiers who had suffered a non-contact ACL injury and 93 age-matched controls completed a self-reported questionnaire relating to intrinsic risk factors (menstrual history, BMI, previous knee injuries, self reported weekly sports participation) and extrinsic risk factors (type of ski used, time of last binding adjustment, snow condition, weather and slope difficulty). A logistic regression model revealed the following independent ACL injury risk factors for female recreational skiers: icy snow conditions (odds ratio, 24.33; 95% confidence interval, 6.8–86.5, $P<0.001$), skiing during snowfall (odds ratio, 16.63; 95% confidence interval, 1.8–152.1, $P=0.013$), use of traditional skis (odds ratio, 10.49; 95% confidence interval, 2.0–54.5, $P=0.005$), and preovulatory phase of menstrual cycle (odds ratio, 2.59; 95% confidence interval, 1.2–5.5, $P=0.013$). In conclusion, ACL injuries in female recreational skiers are the result of a complex interaction of intrinsic and extrinsic risk factors.

Introduction

Knee injuries account for one third of all adult alpine skiing injuries [9] with decisive gender differences in rates of knee injury. For ACL injuries in alpine skiing an incidence of 0.4 per 1 000 skier visits has been reported [4]. Female recreational and competitive skiers have twice the knee injury incidence of male skiers and ACL injury risk is 3 times greater in female skiers [4, 8, 9, 20]. This gender difference may be related to intrinsic risk factors (hormonal, anatomical and neuromuscular) which distinguish males from females [5, 11, 17]. However, according to the comprehensive model for injury causation by Bahr and Krosshaug [3], an ACL injury is likely to be the result of a complex interaction of intrinsic and extrinsic factors. While intrinsic risk factors include, e.g., age, gender, skill level, previous injuries, and risk taking behaviour, extrinsic risk factors in alpine skiing include the environment (snow and weather conditions) and equipment (type of ski or binding) [3, 8, 9]. Johnson et al. [14] speculated that the introduction of carving skis would increase knee injuries, but gender-specific knee injury rates have not changed since the introduction of carving skis [9]. To our knowledge, the interaction of intrinsic and extrinsic factors in recreational alpine skiing ACL injuries has not been examined. We hypothesized that interactions between intrinsic and extrinsic factors induce ACL injuries in recreational female skiers. Therefore, the objective of this study was to investigate the complex interaction of potential intrinsic and extrinsic risk factors in ACL-injured recreational female skiers.

Material and Methods

This study was conducted as a retrospective case-control study of female recreational alpine skiers in the 2006/2007 and 2007/2008 winter seasons in a ski resort in the western part of Austria. The study was performed in conformity with the ethical standards of the 1975 Declaration of Helsinki and with the ethical standards of this journal [10]. Informed consent was obtained from all subjects prior to the beginning of this research.

Subjects

We used the same cohort described in our previous work [17]. Briefly, ACL injured female recreational alpine skiers were treated in a ski clinic,

accepted after revision
March 01, 2011

Bibliography
DOI http://dx.doi.org/10.1055/s-0031-1275355
Published online: 2011
Int J Sports Med

ISSN 0172-4622

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which is located in close proximity to the ski resort studied. MRI was used for the diagnosis of ACL injury. All MRI findings were confirmed at subsequent surgery. Inclusion criteria were non-contact ACL injuries. Subjects were excluded if they were in menopause or used hormone stimulating medications other than oral contraceptives (OC). A total of 93 cases fulfilled the inclusion criteria. 277 controls were randomly selected in same ski area on 5 different days over a period of 2 months in the 2007/2008 winter season. More than 90% of the selected skiers participated. The menstrual cycle could be classified in only 157 controls due to exclusion criteria and missing data. Out of this cohort 93 uninjured controls were randomly matched to the cases by age. Uninjured controls answered the same questions as the ACL-injured females excluding the injury section.

Questionnaire

We recorded information on age, height, weight, body mass index (BMI) and previous knee injuries of either leg for all persons. All injured subjects received and completed the questionnaire within 2 days of injury occurrence with a physician present. We classified self-reported previous knee injuries according to their severity. Only grade II and III injuries of ligaments, meniscus and cartilage were considered as previous knee injuries. Duration of exercise per week (less than 1 h vs. more than 1 h) was recorded as another intrinsic risk factor according to Burtscher et al. [8]. Additionally, oral contraceptive (OC) use and menstrual history data were recorded using a questionnaire developed and validated by Wojtys et al. [22]. This questionnaire included questions on the age at start of menstruation, date of last menstruation, average length of menstruation, and the use of OC. We divided the menstrual cycle into preovulatory and postovulatory phase for OC users and non-users according to other studies [5, 12].

Relating to equipment, we differentiated between traditional and carving skis. Carving skis are shorter (below body height) and have more sidecut compared to traditional skis. Carving skis are narrow at the waist and wider at the tip and tail, giving them a parabolic shape [16]. The elapsed time period from the most recent binding adjustment by a ski service professional (less than 12 months vs. more than 12 months) was also recorded according to Burtscher et al. [9].

Environmental factors consist of snow conditions (fresh snow, grippy, icy, slushy/soft), difficulty of the downhill slope (easy, moderate, hard), and weather (sunny, overcast, snowfall) according to Burtscher et al. [8]. Controls rated the difficulty and the snow conditions of their preferred slopes as well as the overall weather conditions on the day of questioning, ACL injured females rated environmental factors at the time of their accident.

Statistical analysis

Unpaired t-tests and Mann-Whitney-U-test were used to compare cases and controls by age, height, weight, and BMI. Chi-square tests were used to assess different frequencies between groups with regard to oral contraceptive use, phase of menstrual cycle, previous knee injuries, physical activity, type of ski, time since last binding adjustment, snow conditions, difficulty of slope, and weather. Environmental factors with more than 2 categories were binary coded for every single category to achieve univariate odds ratios. Factors with $P<0.1$ were additionally evaluated using a stepwise forward logistic regression analysis to estimate adjusted odds ratios (OR) and their 95% confidence intervals (CI) for ACL injury risk in female recreational skiers. All P-values were two-tailed and values less than 0.05 were considered to indicate statistical significance.

Results

Table 1 shows the characteristics and univariate OR of the intrinsic and extrinsic risk factors. While cases and controls did not differ in age, height and weight ($P>0.05$), BMI was significantly higher in ACL injured female skiers ($P=0.044$).

OC use ($P>0.05$) did not affect the ACL injury risk, but the phase of menstrual cycle showed a significant association ($P<0.03$). The risk of sustaining an ACL injury is unadjusted 1.9 fold higher in the preovulatory phase compared to the postovulatory phase. No significant differences in cases and controls were found with regard to previous knee injuries ($P=0.357$) and physical activity ($P=0.988$).

Skiing with traditional skis showed an unadjusted 7.4 higher ACL injury risk ($P=0.003$) compared to carving skis. No significant difference was seen in elapsed time period from the most recent binding adjustment between cases and controls ($P>0.05$).

Icy slopes, difficult (black) slopes, and snow fall significantly increased ACL injury risk in the injured skiers, as 41.9% of those injured skied on icy terrain, 13% on a black slope, and 9.8% during snowfall. The respective percentages reported in the control group were 3.3%, 2.2% and 1.1%. A significantly lower risk (OR <0.5, $P<0.03$) was seen on grippy or slushy snow, on a moderate (red) slope, and on sunny days.

Factors with $P<0.1$ (BMI, phase of menstrual cycle, type of ski used, all snow conditions, moderate and hard slope difficulty, sunny weather and snowfall) were included in a stepwise forward logistic regression model (**Table 2**), except for age, because cases and controls were matched with regard to age.

Multivariate regression analysis revealed 4 factors to be significantly predictive for ACL injury risk in female skiers. The adjusted ACL injury risk was multiplied by 24.3 (CI: 6.8–86.5) on icy terrain, by 16.6 (CI: 1.8–152.1) in snowfall, by 10.5 (CI: 2.0–54.5) with traditional skis, and by 2.6 (CI: 1.2–5.5) in the preovulatory phase of menstrual cycle.

Discussion

The interaction of several intrinsic and extrinsic risk factors on the likelihood of sustaining an ACL injury in female recreational skiing was investigated. Icy snow conditions, skiing during snowfall, using traditional skis and being in the preovulatory phase of their menstrual cycle were found to be independent risk factors associated with an ACL injury in female skiers.

Skiing on icy terrain showed a 24-fold higher risk of sustaining an ACL injury. Icy terrain was the most frequently reported snow condition related to ACL injury with about 42% of the cases. The injury risk on icy terrain might be overestimated in this study, because controls were asked on only 5 days about the actual snow conditions, where only 3.3% of controls reported icy conditions. However, unpublished data of our annual ski accident survey in this ski area revealed that 3.7% of all registered injuries occurred on icy slopes. Skiers have less edge control on ice than on grippy snow, leading to easier loss of balance and falls which can result in an ACL injury. Järvinnen et al. [13] reported that 17

	Cases (n = 93)	Controls (n = 93)	Odds ratio (95 % CI) univariate	p-value
intrinsic risk factors				
age, mean (sd)	38.8 (7.9)	38.1 (6.6)		0.093
body composition				
height, mean (sd)	167.0 (5.6)	168.4 (6.4)		0.115
weight, mean (sd)	67.1 (9.7)	65.9 (9.6)		0.282
BMI, mean (sd)	24.1 (3.5)	23.3 (3.5)		0.044
hormonal factors				
OC use, yes (%)	32 (34.4)	33 (35.5)	0.9 (0.5–1.7)	0.878
menstrual phase preovulatory phase, yes (%)	53 (57)	38 (40.9)	1.9 (1.1–3.4)	0.028
health and physical fitness				
previous knee injury, yes (%)	20 (23.3)	27 (29.3)	0.7 (0.4–1.4)	0.357
missing data	7	1		
physical activity ≤ 1 h/week, yes (%)	33 (37.9)	35 (38)	0.9 (0.5–1.8)	0.988
missing data	6	1		
extrinsic risk factors				
equipment related factor				
ski type				
traditional ski (%)	13 (14)	2 (2.2)		
carving ski (%)	80 (86)	91 (97.8)	7.4 (1.6–33.8)	0.003
binding adjustment				
≤ 1 year (%)	60 (66.7)	61 (66.3)		
> 1 year (%)	30 (33.3)	31 (33.7)	1.0 (0.6–1.9)	0.959
missing data	3	1		
environmental factors				
snow conditions				
fresh snow, yes (%)	15 (17.4)	8 (8.8)	2.2 (0.9–5.5)	0.087
grippy, yes (%)	29 (33.7)	60 (65.9)	0.3 (0.1–0.5)	0.000
icy, yes (%)	36 (41.9)	3 (3.3)	21.1 (6.2–72.1)	0.000
slushy/soft, yes (%)	6 (7)	20 (22)	0.3 (0.1–0.7)	0.005
missing data	7	2		
difficulty of the downhill slope				
easy (blue), yes (%)	25 (27.2)	21 (22.6)	1.3 (0.7–2.5)	0.470
moderate (red), yes (%)	55 (59.8)	70 (75.3)	0.5 (0.3–0.9)	0.024
hard (black), yes (%)	12 (13)	2 (2.2)	6.8 (1.5–31.4)	0.005
missing data	1			
weather				
sunny, yes (%)	64 (69.6)	78 (84.8)	0.4 (0.2–0.8)	0.014
overcast, yes (%)	19 (20.7)	13 (14.1)	1.6 (0.8–3.4)	0.243
snowfall, yes (%)	9 (9.8)	1 (1.1)	9.9 (1.2–79.6)	0.009
missing data	1	1		

Table 1 Characteristics and univariate odds ratios of intrinsic and extrinsic risk factors in ACL injured female skiers.

Risk factor	Coefficient	Standard error	*df*	*P*	Odds ratio multivariate	95 % CI
snow conditions						
icy	3.192	0.647	1	0.000	24.33	6.8–86.5
weather conditions						
snowfall	2.811	1.129	1	0.013	16.63	1.8–152.1
ski type						
traditional ski	2.350	0.840	1	0.005	10.49	2.0–54.5
menstrual cycle phase						
preovulatory phase	0.953	0.385	1	0.013	2.59	1.2–5.5
intercept	−17.188	3.337	1	0.000	0.000	

Table 2 Multivariate odds ratios of intrinsic and extrinsic risk factors in ACL injured female skiers.

of 51 ACL injured downhill and cross-country skiers had lost balance on an unexpected slippery spot and 14 stated that icy conditions had caused their fall. Bouter et al. [6] also demonstrated an elevated risk of ski injuries on icy ski slopes.

Snowfall increased ACL injury risk 17-fold in the present study. In accordance, we recently demonstrated a 2-fold prevalence for knee injured females when skiing during snowfall compared to females with other injuries (15.4 vs. 8.6 %; p = 0.001) [19]. In addition, Aschauer et al. [2] showed a higher injury risk of 1.12 % (10 injuries in 13 421 runs) during strong snowfall compared to 0.55 % (60 injuries in 167 045 runs) in sunny conditions. In this study about 10 % of ACL injuries occurred during snowfall and about 70 % were on sunny days being in agreement with another study by our group [18]. Burtscher et al. [8] found that 63 % of women's knee injuries and 64 % of skiing injuries in general occurred in sunny conditions. Our results indicate that poor visibility and light conditions during snowfall increase the ACL injury risk which might be due to an increased friction with

increasing snowfall. However, skiers prefer to ski when it is sunny with more skiers on the slopes [2,8] resulting in an increased prevalence of ACL injuries.

Regarding equipment related factors, we compared the use of carving skis with traditional skis. Our logistic regression model revealed an adjusted 10.5 higher risk for sustaining an ACL injury when skiing with traditional skis. In accordance with our findings, recent studies revealed even a lower risk for sustaining an ACL injury when skiing with carving skis compared to traditional skis [15,16]. A study conducted in a German ski clinic found that carving skiers suffered significantly less injuries to the knee joint (37.6% vs. 41.8%) and less ACL ruptures (11.4% vs. 14.3%) compared to those with traditional skis [15]. We assume that this result may be partly related to changes in the distribution of ACL injury mechanisms with the introduction of the short and shaped carving ski [18]. While in female traditional skiers the backward twisting fall ("phantom foot") was the dominant ACL injury mechanism [13], the forward twisting fall was shown to be the most common injury mechanism in female carving skiers [18].

Regarding hormonal factors, no significant association between ACL injuries and OC use could be detected. These findings are well in accordance with the study by Agel et al. [1]. Therefore, according to other studies in this research area [12], we divided the combined group of OC users and nonusers in preovulatory and postovulatory groups. The result of the logistic regression in this study revealed an adjusted odds ratio of 2.6 for a higher ACL injury risk in the preovulatory phase when analysing menstrual history data. In comparison, Beynnon et al. [5] revealed that the likelihood of recreational female skiers without OC use is estimated to be 3 times greater in the preovulatory phase when analysing serum concentrations of progesterone and estradiol. Apart from menstrual cycle phase, no other intrinsic factor showed a significant association with a higher ACL injury risk in female skiers.

In this study, 1 out of 5 intrinsic factors and 3 out of 12 extrinsic factors were predictive of future ACL injury risk in recreational female skiers. While most intrinsic risk factors used in the present study are hard to modify, extrinsic risk factors can be considered a lot easier by female skiers, e.g., avoiding icy spots. However, the influence of artificial snow and grooming practice in ski areas on glaciations of ski slopes with regard to knee injury risk should be also investigated in future.

There are few limitations regarding our retrospective design using a self-reported questionnaire which have to be considered. Because the study only included patients from the ski clinic we can not exclude a possible selection of ACL injured skiers. But most of the knee injuries occurring in the study area were treated in the ski clinic and there are no indications of any source of selection. In general, a prospective design including a clinical examination of the skiers would have been preferable in order to identify potential intrinsic risk factors. Regarding traditional skis as a potential risk factor also aspects like ski preparation have to be considered because of the age of traditional skis which have not been produced for several years. With regard to the factor slope difficulty some uncertainties may arise because we compared reported data on preferred slope difficulties for the control group and the actual slope difficulty where persons injured their ACL.

Regarding environmental factors, ACL injured skiers were matched to uninjured controls during different ski seasons. This historical comparison hindered the comparison of possible extrinsic risk factors such as weather and snow conditions. However a comparison of weather data of this period over the 2 seasons, provided by the ZAMG (Zentralanstalt für Metereologie und Geodynamik, Dr. K. Gabl), showed no differences in sun hours, precipitation, and storm force while average temperature was somewhat lower in the second season. Furthermore, homogeneous slope conditions in ski areas are provided with the production of artificial snow and intensive preparation and grooming of slopes. Additionally, in certain cases poor snow and weather conditions may have been misjudged because ACL injured skiers may look for an explanation as to why the injury occurred. In general, self-reporting to questions might lead to underreporting or overreporting of health-risk behaviours affected by cognitive and situational factors [7] as Sulheim et al. [21] observed also a tendency towards underestimation of the individual skiing ability, especially among female skiers.

In conclusion, the current results indicate that skiing on icy terrain, skiing during snowfall, using traditional skis and being in the preovulatory phase of their menstrual cycle may contribute to an increased ACL injury risk in females. With regard to the results, preventive intervention strategies should consider personal factors as well as equipment related and environmental factors.

Acknowledgements

The authors gratefully acknowledge support for this study from the Tiroler Wissenschaftsfond (TWF). In addition, this study was supported by a grant of the OSM Research Foundation. We would also like to extend our thanks to Dr. Karl Gabl for the comparison of the weather data.

References

1 *Agel J*, *Bershadsky B*, *Arendt EA*. Hormonal therapy: ACL and ankle injury. Med Sci Sports Exerc 2006; 38: 7–12
2 *Aschauer E*, *Ritter E*, *Resch H*, *Thoeni H*, *Spatzenegger H*. Injuries and injury risk in skiing and snowboarding. Unfallchirug 2007; 110: 301–306 (in German)
3 *Bahr R*, *Krosshaug T*. Understanding injury mechanisms: a key component of preventing injuries in sport. Br J Sports Med 2005; 39: 324–329
4 *Beynnon BD*, *Ettlinger CF*, *Johnson RJ*. Epidemiology and mechanisms of ACL injury in alpine skiing. In: Hewett TE, Shultz SJ, Griffin LY (eds). Understanding and preventing noncontact ACL injuries. American Orthopaedic Society for Sports Medicine. Human Kinetics; 2007; 183–188
5 *Beynnon BD*, *Johnson RJ*, *Braun S*, *Sargent M*. The relationship between menstrual cycle phase and anterior cruciate ligament injury: a case-control study of recreational alpine skiers. Am J Sports Med 2006; 34: 757–764
6 *Bouter LM*, *Knipschild PG*, *Volovics A*. Personal and environmental factors in relation to injury risk in downhill skiing. Int J Sports Med 1989; 10: 298–301
7 *Brenner ND*, *Billy JOG*, *Grady WR*. Assessment of factors affecting the validity of self-reported health-risk behavior among adolescents: evidence from the scientific literature. J Adolesc Health 2003; 33: 436–457
8 *Burtscher M*, *Sommersacher R*, *Ruedl G*, *Nachbauer W*. Potential risk factors for knee injuries in alpine skiers. Journal of ASTM International 2009; 6: 1–4
9 *Burtscher M*, *Gatterer H*, *Flatz M*, *Sommersacher R*, *Woldrich T*, *Ruedl G*, *Hotter B*, *Lee A*, *Nachbauer W*. Effects of modern ski equipment on the overall injury rate and the pattern of injury location in Alpine skiing. Clin J Sport Med 2008; 18: 355–357
10 *Harriss DJ*, *Atkinson G*. International Journal of Sports Medicine – Ethical Standards in Sports and Exercise Science Research. Int J Sports Med 2009; 30: 701–702

11 *Hewett TE*, *Meyer GD*, *Ford KR*. Anterior cruciate ligament injuries in female athletes: Part 1, mechanism and risk factors. Am J Sports Med 2006; 34: 299–311
12 *Hewett TE*, *Zazulak BT*, *Myer GD*. Effects of the menstrual cycle on anterior cruciate ligament injury risk: a systematic review. Am J Sports Med 2007; 35: 659–668
13 *Järvinen M*, *Natri A*, *Laurila S*, *Kannus P*. Mechanisms of anterior cruciate ligament ruptures in skiing. Knee Surg Sports Traumatol Arthrosc 1994; 2: 224–228
14 *Johnson RJ*, *Ettlinger CF*, *Shealy JF*, *Meader C*. Impact of super side cut skis on the epidemiology of skiing injuries. Sportverletzung Sportschaden 1997; 11: 150–152
15 *Köhne G*, *Kusche H*, *Schaller C*, *Gutsfeld P*. Ski accidents-changes since introduction of carving ski. Sportorthopädie Sporttraumatologie 2007; 23: 63–67 (in German)
16 *Merkur A*, *Whelan KM*, *Kuah E*, *Choo P*. The effect of ski shape on injury occurrence in downhill skiing. Skiing Trauma and Safety: 14th Vol, Johnson RJ, Lamont MK, Shealy JE, (eds). ASTM 2003, Saline, MI: 129–139
17 *Ruedl G*, *Ploner P*, *Linortner I*, *Schranz A*, *Fink C*, *Sommersacher R*, *Pocecco E*, *Nachbauer W*, *Burtscher M*. Are oral contraceptive use and menstrual cycle phase related to anterior cruciate ligament injury risk in female recreational skiers? Knee Surg Sports Traum Arthrosc 2009; 17: 1065–1069
18 *Ruedl G*, *Linortner I*, *Schranz A Fink C*, *Schindelwig K*, *Nachbauer W*, *Burtscher M*. Distribution of injury mechanisms and related factors in ACL injured female carving skiers? Knee Surg Sports Traum Arthrosc 2009; 17: 1393–1398
19 *Ruedl G*, *Fink C*, *Schranz A*, *Sommersacher R*, *Nachbauer W*, *Burtscher M*. Impact of environmental factors on knee injuries in male and female recreational skiers. Scan J Med Sci Sport 2011, (in press)
20 *Stevenson H*, *Webster J*, *Johnson RJ*, *Beynnon B*. Gender differences in knee injury epidemiology among competitive alpine ski racers. Iowa Orthop J 1998; 18: 64–66
21 *Sulheim S*, *Ekeland A*, *Bahr R*. Self-estimation of ability among skiers and snowboarders in alpine skiing resort. Knee Surg Sports Traumatol Arthrosc 2007; 15: 665–670
22 *Wojtys EM*, *Huston LJ*, *Lindenfeld TN*, *Hewett TE*, *Greenfield ML*. Association between the menstrual cycle and anterior cruciate ligament injuries in female athletes. Am J Sports Med 1998; 26: 614–619