A Prospective Injury Surveillance Study on Ski Touring

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Background: Ski touring is an outdoor sport with growing popularity in alpine countries. Information about injuries in ski touring is limited.

Purpose: To determine injury rates, mechanisms, causes, and risk factors in ski touring.

Study Design: Descriptive epidemiology study.

Methods: Between November 2015 and May 2016, a total of 191 participants from the Alps region were prospectively tracked via personalized online questionnaires. Injury rates were calculated per 1000 hours of sports exposure. Risk factors were assessed per multivariate logistic regression analysis.

Results: A total of 3900 ski tours were performed, with 10,955 hours and 4,108,503 m in height ascension (uphill) recorded. The overall injury rate was 2.5 injuries per 1000 hours of ski touring. A total of 27 injury-events were reported, of which 18 (67%) were classified as mild, 7 (26%) as moderate, and 2 (7%) as severe. Hands (28%) and knees (16%) were the most commonly involved anatomic regions. Most injuries were limited to the soft tissue, such as bruises (31%) and abrasions (18%). Significantly more injuries happened during the descent (n = 17; 63%) than during the ascent (n = 6; 22%) (odds ratio, 5.96; $P = .004$), while poor weather conditions, icy surface, and inattentiveness were the most often reported reasons for injury. Sidecountry ski touring was identified as the only significant independent risk factor for injury ($P < .001$).

Conclusion: In this prospective injury surveillance study, the majority of ski touring injuries were mild and limited to the soft tissue. Ski touring injuries were more likely to happen during the descent of a tour, and sidecountry ski touring was the only significant independent risk factor for injury. Bad weather, icy surface, and inattentiveness were found to be the leading causes for an injury-event in this study.

Keywords: injury surveillance; sports injury; epidemiology; prevention; ski touring; alpine sports

Over the past few years, ski touring has become an emerging winter sport especially in alpine regions. According to current estimates of the German and Austrian Alpine Association, there are about half a million ski tourers in Germany and up to 700,000 ski tourers in Austria.[9,27]

Ski touring involves uphill and downhill travel without needing to remove the skis.[6,39] It is a hybrid between alpine skiing and (snow) hiking and overlaps with both nordic and alpine forms. As such, a characteristic of ski touring is a free heel in an alpine ski binding, allowing for traversing and ascending flat or extremely steep terrain.[6,39] Climbing skins or friction aids are typically used to provide sufficient grip during the ascent.[6,39] The descent is similar to alpine skiing; however, the touring bindings are set to hold the boot heel firmly to the ski.[8]

Ski touring is generally distinguished as frontcountry, sidecountry, and alpine or backcountry.[6,39] Frontcountry is defined as ski touring within the boundaries of a ski area, with ski lifts and emergency services close at hand.[6,39] Sidecountry is defined as ski touring outside marked ski area boundaries yet accessible via ski lift, and backcountry ski touring is defined as navigating and skiing in remote areas outside the boundaries of the ski terrain.[6,39] Backcountry ski touring is more time-consuming, owing to longer transportation to the high alpine terrain, thus explaining why frontcountry ski touring in a skiing area has become more popular in recent years as an after-work activity.[1,17,28,40] In addition to the ability of skiing off-piste, backcountry ski touring requires navigation skills and knowledge to assess snow conditions to minimize the risk of avalanche-related accidents.[6,39] Additional safety equipment, including

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avalanche- and rescue-specific equipment, is also recommended for ski touring in remote areas.[23]

Little is known about injury rates and causes in ski touring, and presently, only 1 cross-sectional questionnaire-based study about frequencies and causes of injuries in frontcountry ski touring is available.[34] In that retrospective study, among a cohort of 451 so-called slope tourers, an injury rate of about 13% was calculated, with self-inflicted falls being the most common reported injury cause. Hence, the current study sought to determine common injury rates, patterns, causes, and risk factors in all ski touring disciplines.

METHODS

For this prospective observational study, institutional review board approval was obtained, and all participants gave written consent.

Study Population

For methodological purposes, participants were selected according to the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) criteria.[38] The study was conducted during 1 ski touring season from November 2015 to May 2016. Participants had to be at least 18 years old and had to perform at least 1 ski tour in the observed season to be included. Initially 214 participants were prospectively being tracked; however, 23 were excluded as they did not perform any ski tour during the observed season. The final analysis included 191 participants.

Recruitment of participants was based on previous sports injury surveillance studies,[11,12] and participants were contacted through the registries of the Austrian Skiing Association and the Austrian, German, and Swiss Alpine Clubs. Given the substantial geographic and climatic differences among several mountain chains, the aim was to include only participants who conducted their ski tours in the Alps region.

Data Acquisition

All data were obtained with an encrypted, anonymized, and personalized online-based questionnaire.[22] General information—including age, sex, body dimensions, preferred ski touring territory, years of ski touring experience, skill level, and skiing behavior—was gathered prior to the study. The definition of each skill level was established in a consensus session with a ski touring expert group. A modified classification was constructed according to previous sports epidemiology studies.[11,12] Skiing behavior was categorized as "very careful," "cautious," "willing to take some risks," and "risk taker."[11] Participants were divided into 3 groups, as beginner, advanced, and expert ski tourers. Further details are provided in Table 1.

TABLE 1
Classification of Personal Level of Performance

Variable	Beginner	Advanced	Expert
Experience	≤1 ski touring season	≥2 ski touring seasons	Ski touring guide
Preferred terrain	Front- and sidecountry	Any terrain	Any terrain
Competition	None	Nonprofessional	International

At the end of each month within the ski touring season, participants filled out an activity-based online questionnaire.[4] The information being obtained included number of hours of ski touring, number of tours performed, meters ascended, terrain and snow conditions, off-piste training, equipment employed, avalanche accidents, and sustained injuries. Participants could refer to the terrain as frontcountry, sidecountry, or backcountry tours. Snow conditions were classified into "fresh snow/powder," "good grip," "slushy/muddy," and "icy." Off-piste training was defined as any workout besides ski touring and included cardiovascular training, strength training or stretching, and balance training. Ski touring equipment was defined as every type of equipment used outside of conventional skiwear, such as a ski suit, skis, and ski poles (Figure 1).

In case of a reported injury-event, additional information regarding the circumstances, affected body part, type of injury, injury severity, and mechanisms of injury was assessed. Multiple responses regarding the injury circumstances and mechanisms were possible. Injury circumstances included information about the phase of the ski tour (ascent, descent, or between), time of day, weather and snow conditions, and the ski touring equipment employed. Questions about injury mechanism involved information about the ski touring accident, such as tilting, slipping, or colliding, and also material-related information, such as inadvertent release of the binding or technical failure (Figure 2).

With regard to injury mechanism, questions regarding the physical state during the accident were asked, as well as any influencing factors such as inattentiveness.

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Ethical approval for this study was obtained from the ethics committee for the province of Salzburg, Austria (415-EP/73/668-2016).

Figure 1. Ski touring equipment (from left to right). First row: avalanche backpack, avalanche shovel, headlamp, avalanche peep, ski jacket, helmet. Second row: avalanche probe, digital avalanche transceiver, maps, ski underwear, ski glasses, climbing skins. Third row: first-aid kit, sunscreen, knife, water, thermos bottle, mobile phone, scarf, bivy bag, crampons. (©Kurt Keinrath)

Furthermore, the participants were asked about their rescue, medical treatment, and the injury-related time of sports impairment.

Throughout the season, weekly checks of ski touring–related media were conducted to ensure that none of the ski tourers who had failed to follow up had suffered a fatal ski touring injury.

A ski tour was divided into ascent and descent and distinguished as frontcountry, sidecountry, or backcountry (Figure 3).

Injury Rate Calculation

According to the consensus statements of Fuller et al,[13,14] an injury was defined as any physical complaint that resulted from training or competition, regardless of medical treatment requirement or absence from sports.

The injury rate was calculated per 1000 hours of sports exposure.[13,14,34,38] The term *exposure* comprised everything between the start and the very end of a ski tour.[11,12] An injury-event was defined as an incidence with possibly >1 injury type or affected anatomic location involved.[11,12]

The severity of injury was defined according to the extent of sports impairment.[11,12] Injuries causing no disruption to training or competition, such as bruises or contusions, were considered mild. Injuries resulting in a partial restriction from usual level of performance while still allowing participation in sports were defined as moderate. Injuries resulting in total absence from sports for a certain time span were classified as severe, and injuries leading to permanent disability or death were considered fatal.[11,12]

According to Meeuwisse,[24] risk factors were divided into 2 categorical types: intrinsic and extrinsic. Intrinsic factors included maturational stage, somatotype, and previous injuries, and extrinsic factors referred to equipment, type of tour, and environment. Intrinsic risk factors may predispose an athlete to an injury, whereas extrinsic risk factors are the trigger for an injury-event.[5,24]

Statistical Analysis

Data were tested regarding normal distribution according to the Shapiro-Wilk test. Statistical significance between several means was assessed with an unpaired Student *t* test for normally distributed data and the Mann-Whitney *U* test for nonnormally distributed data. Chi-square tests and Fisher exact tests (if $n < 5$) were used to analyze categorical variables. Univariate risk factors were quantified with odds ratios and a corresponding 95% CI. Multivariate logistic regression analysis was conducted to determine independent intrinsic and extrinsic risk factors. Goodness of fit of the binary logistic regression models was assessed via the Hosmer-Lemeshow test. All statistical tests were 2-sided, and *P* values <.05 were considered statistically significant.

Figure 2. The free heel in the ski binding allows for traversing and ascending steep terrain. (©argonaut.pro)

RESULTS

Study Population

Of the 191 included participants, 27 (14%) performed only 1 ski tour in the ski touring season. The mean age was 33.7 years (range, 18-70 years), and 112 participants (59%) were men. Participants originated from 8 countries. The skill level ranged from beginner to expert, including 48 beginners (25%), 120 advanced ski tourers (63%), and 23 experts (12%).

The mean experience in ski touring was 11.3 years (range, 0-40 years). More than two-thirds of the study participants (n = 131; 69%) stated that they performed regular off-piste training; most of those (n = 125; 65%) performed cardiovascular or strength training, whereas 60 (31%) did not work out regularly. The most frequently employed types of equipment were climbing skins or friction aids (n = 176; 92%), avalanche transceivers (n = 166; 87%), avalanche shovels (n = 161; 84%), probes (n = 160; 84%), gloves (n = 121; 63%), and helmets (n = 112; 59%).

Injury Rates, Patterns, and Severity

A total of 3900 ski tours were performed: 1446 as frontcountry, 2064 as sidecountry, and 390 as backcountry. During a total of 10,955 hours, 4,108,503 m in height ascension (uphill) was performed. The overall injury rate was 2.5 injuries per 1000 hours of sports exposure or 6.7 injuries per 1000 ski tours. There were 27 injury-events (14%), of which 18 (67%) were classified as mild, 7 (26%) as moderate, and 2 (7%) as severe. No fatal injuries were recorded. The 27 injury-events involved 32 anatomic regions and 40 types of injuries (Tables 2 and 3). The hand (28%) and knee (16%) were the most commonly injured anatomic regions. Most injuries were limited to the soft tissue, such as bruises (31%) and abrasions (18%). No ligamentous knee injury was reported. Three participants (2%) suffered from skier's thumb (lesion of the ulnar collateral ligament of the first metacarpophalangeal joint). All 3 participants were treated nonoperatively and returned to physical activity within 3 months. Two participants sustained a severe injury requiring surgical treatment: one to a syndesmotic malleolar fracture with return to physical activity after 90 days and the other to a radial meniscal tear with return to physical activity after 4 weeks. The participant with the syndesmotic malleolar fracture had to be rescued with a Ski-Doo (snowmobile); all other injured participants were able to descend independently.

Injury Circumstances, Mechanisms, and Risk Factors

The most frequently stated reason for an injury was icy surface (n = 14; 52%), followed by poor weather conditions (n = 10; 37%) and inattentiveness (n = 9; 33%). No accidents involving avalanches were reported. Participants were significantly more likely to get injured during the descent than the ascent of a tour (1.6 vs 0.5 injuries/1000 h; odds ratio = 5.96; 95% CI, 1.8-19.7; $P = .004$). Although not statistically significant, advanced ski tourers had a higher injury rate (3.0 injuries/1000 h exposure) than experts (1.1 injuries/1000 h; $P = .17$) and beginners (1.8 injuries/1000 h; $P = .34$). The injury rate during frontcountry (3.0 injuries/1000 h) and sidecountry (2.8 injuries/1000 h) ski touring was higher than that with backcountry ski touring (0.6 injuries/1000 h). These comparisons, however, did not reach statistical significance ($P = .11$ and .12, respectively).

In the most common scenario of an injury-event, an advanced ski tourer sustained an injury during the descent of an icy sidecountry ski tour (Table 4).

The only factor that significantly influenced the regression model was sidecountry ski touring ($P < .001$) (Table 5). The Hosmer-Lemeshow test confirmed the goodness of fit of the model ($P = .656$).

DISCUSSION

The key finding of this study is that ski touring is associated with an injury rate of 2.5 injuries per 1000 hours of sports exposure and injuries are, for the most part, mild and limited to the soft tissue. Another main finding is that the odds ratio for injury during the descent is 6-fold higher compared with the ascent of a tour. The only significant independent risk factor for injury was sidecountry ski touring.

Figure 3. Ascent during a backcountry ski tour in a remote area. (©Stefan Fröhlich)

TABLE 2
Affected Anatomic Regions During Injury-Events (n = 32)

Anatomic Region	n	%[a]	Injury Rate[b]
Hand	9	28	0.8
Knee	5	16	0.5
Foot/ankle	3	9	0.3
Thigh	3	9	0.3
Hip	2	6	0.2
Arm	2	6	0.2
Ribs/thorax	2	6	0.2
Calf	2	6	0.2
Adductors	1	3	0.1
Head/face	1	3	0.1
Neck	1	3	0.1
Shoulder	1	3	0.1

[a]Percentage of all injuries by anatomic region.
[b]Per 1000 hours of sports exposure.

TABLE 3
Types of Injuries During Injury-Events (n = 40)

Type	n	%[a]	Injury Rate[b]
Bruise	12	31	1.1
Abrasion	7	18	0.6
Ligament rupture	5	13	0.5
Muscle strain	4	10	0.4
Joint sprain	3	8	0.3
Cartilage injury	3	8	0.3
Contusion	3	8	0.3
Muscle tear	1	3	0.1
Fracture	1	3	0.1
Other	2	5	0.2

[a]Percentage of all injuries by injury type.
[b]Per 1000 hours of sports exposure.

TABLE 4
Key Characteristics for an Injury[a]

Category	Item	n	%[b]
Skill level	Advanced	21	78
Type of tour	Sidecountry	18	67
Phase of tour	Descent	17	63
Snow condition	Icy	14	52

[a]Multiple answers were possible.
[b]The number of the item divided by total number of injuries.

The overall observed injury rate can also be calculated as 6.7 injuries per 1000 ski tours, which seems comparable with 6 injuries per 1000 ski tours in a previously published cross-sectional study on frontcountry ski touring.[34] The reported injury rate in cross-country skiing was 0.5 per 1000 skiing days in the recreational field and between 0.02 and 0.1 per 1000 skiing days in professional cross-country skiing.[2,19] The majority of the injuries described by previous cross-country skiing studies were also mild and limited to the soft tissue.[19] Although the unit of the injury rate is different, the injury rates in cross-country skiing are much lower than the injury rates described in this study. In recreational alpine skiing, the previously described injury rate was also lower, with <1 injury per 1000 skiing days in the Alps region.[7,34,38]

A higher injury rate than in cross-country and recreational skiing seems in accordance with the fact that ski touring is an adventurous outdoor sport and involves skiing in off-piste terrain. Off-piste skiing appears to be associated with a self-reported risky behavior among skiers and

TABLE 5
Multivariate Logistic Regression Analysis of Intrinsic and Extrinsic Risk Factors for Ski Touring Injury

Item	Coefficient	SE	P^a
Intrinsic risk factor			
Age	0.032	0.025	.637
Sex	–0.432	0.415	.537
Level of performance[b]	–0.113	0.384	.651
Off-piste training	0.443	0.424	.292
Skiing behavior[c]	0.062	0.310	.643
Ski touring experience, y	–0.030	0.025	.092
Extrinsic risk factor: ski touring			
Frontcountry	–0.049	0.027	.056
Sidecountry	–0.052	0.010	**<.001**
Backcountry	–0.032	0.023	.096

[a]Bold indicates statistical significance ($P < .05$).
[b]Participants were divided into 3 groups: beginner, advanced, and expert ski tourers.
[c]Skiing behavior was categorized as "very careful," "cautious," "willing to take some risks," and "risk taker."

snowboarders.[30] Accordingly, sidecountry ski touring was the only significant independent risk factor for injury in our study. These results should be interpreted in light of the fact that off-piste skiing by means of backcountry ski touring is underrepresented and might have contributed to underestimation of the injury rate. Further studies analyzing high-volume sidecountry and backcountry ski touring are necessary to provide meaningful prevention strategies for off-piste skiing.

Although in this study the majority of injuries were mild and limited to soft tissue, ski touring is neither harmless nor a low-risk sport. In 2016, there were 28 fatal accidents during ski touring in the Austrian Alps.[26] The present results, albeit in a limited sample size, revealed no fatal accidents nor injury-events related to an avalanche. Nevertheless, it is crucial to be aware of the risk of avalanches, as backcountry skiers are the most common groups involved in avalanche accidents and their lethal consequences.[29] In 2016, there were 12 fatal avalanche accidents in ski touring recorded in Austria.[26] Geographical knowledge and knowledge in avalanche risk assessment, small group size, and specific equipment, such as avalanche airbags, avalanche transceivers, shovels, and probes, should be a prerequisite when performing sidecountry or backcountry ski tours.[16,41]

Icy surface and bad weather were the main reasons for injuries. On an icy surface, skiing grip is diminished, especially while squatting, which increases the risk of slipping, tilting, and falling. Accordingly, lower temperatures and bad weather conditions are associated with a higher injury risk on ski slopes.[3,31] Obtaining information about the weather and snow conditions prior to touring could therefore be a preventive measure. Inattentiveness was found to be another cause for injuries in this study. Athletes should thus take regular breaks and have an adequate intake of nutrition during ski touring to ensure a proper physical and mental state. Although there was no significant association in the present study, off-piste training might be a preventive measure, as increased muscle strength reduces early muscle fatigue and the concomitant risk of injury.[15]

While the difference was not statistically significant, the injury rate in advanced ski tourers (3.0 injuries/1000 h) was higher than in experts (1.1 injuries/1000 h) and beginners (1.8 injuries/1000 h). Previous injury surveillance studies have shown that more experience as such seems to be a preventive measure, as poorer technical skills were associated with injuries.[11,12] According to our definition of performance level, advanced ski tourers are those who perform a high number of ski tours on any terrain without restrictions but remain on a nonprofessional level. Considering oneself advanced might be associated with riskier skiing behavior or an overestimation of one's personal capabilities. Such risk-taking behavior was reported to be associated with higher skiing speeds and increased injury risk.[35]

In this study, about 16% of all reported injuries involved the knee joint. Contrary to our assumption, no ligamentous knee injuries were reported. In recreational skiing, knee injuries make up the majority of injuries.[18,20,33,37] Ligamentous knee injuries in alpine skiing frequently involve the anterior cruciate ligament.[19,21] In skiing, the amount of torsion on the lower extremities is high, thus exposing the knee joint to unphysiological high rotational and shear forces, especially when the binding fails to release during falling.[21,32,36] Since the 1990s, the use of carving skis has evolved, and recent studies have shown that they have a positive influence on the overall injury rate and the rate of knee injuries.[7] In ski touring, skis are broader, resulting in a larger contact area and radii, thus allowing for better control while ascending or descending in untouched areas with deep powder snow. The influence of this different type of ski on the risk for injuries is yet to be investigated. Another feature of ski touring is that powder snow in remote areas makes skiing less aggressive, with less racing character. Moreover, the rather small size of touring groups and the lack of mass tourism bear a lower risk of collision injuries.

A known injury in alpine skiing involves the ulnar collateral ligament of the first metacarpophalangeal joint, also known as skier's thumb.[10,20,25] We observed 3 cases of skier's thumb in this study. All 3 patients were treated nonoperatively and returned to physical activity within 3 months. Prevention strategies are yet to be defined but might involve additional support by gloves protective against forced abduction and hyperextension of the thumb.

The main limitation of this study is that the sample size, as compared with the large number of ski tourers in the alpine region, was relatively small. Another limitation is the questionnaire-based data collection, which might be subject to recall and information bias. The influence of different ski binding systems was not analyzed, and may be a focus for further investigations. Comparability with injury rates of other winter sports was limited, owing to different definitions of the injury rate. Since a ski tour includes an ascent and a descent, the injury rate cannot be properly described per runs and is more precisely expressed per hour. In addition, the number of backcountry ski tours and the subgroup analysis regarding skill levels might have

been underpowered. Further prospective studies with a higher number of participants comparing different alpine regions and territories and showing more detailed subgroup analysis of skill levels and injury severity would be of considerable interest. Finally, we did not have information about phase and snow condition during every ski tour reported. Therefore, we were not able to include those factors in our multivariate analysis.

Nevertheless, the current study is the first prospective trial to analyze injuries in >190 ski touring athletes of the Alps region over the period of 1 ski touring season. Injuries in the present study were defined according to the consensus statement of Fuller et al[13] as any physical complaint resulting from ski touring, regardless of medical treatment requirement or absence from sports. Even injuries that did not result in disruption of ski touring were recorded. Thus, underestimation of injury rates may have been minimized.

CONCLUSION

In this prospective injury surveillance study, the majority of ski touring injuries were mild and limited to the soft tissue. Nevertheless, the overall injury rate was higher than in cross-country skiing and recreational alpine skiing. The most commonly affected anatomic regions were the hand and knee joint. In contrast with alpine skiing, ligamentous knee injuries were uncommon. Ski touring injuries were more likely to happen during the descent of a tour, and sidecountry ski touring was the only significant independent risk factor for injury. Bad weather, icy surface, and inattentiveness were found to be the leading causes for an injury-event in this study.

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