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Injuries among World Cup freestyle skiers

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Running head: Injuries among freestyle skiers

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Abstract

Background: Limited knowledge exists on injuries among professional freestyle skiers.

Objective: To describe the risk of injury and injury patterns among competitive World Cup (WC) freestyle skiers during the competitive season.

Methods: Retrospective interviews were conducted with WC freestyle skiers from 20 nations in a cohort study at the end of the 2006-2007, 2007-2008 and 2008-2009 winter seasons, and all acute injuries occurring during the 4.5 month competitive season were recorded. If an athlete was not present, we interviewed his or her coach or medical personnel.

Results: A total of 291 acute injuries were recorded among 662 WC freestyle skiers. Ninety-three (32%) were severe in nature, defined as >28 days absence from training/competition. This corresponds to 14 (95% CI 11.2 to 16.9) injuries per 100 athletes per season. The most frequently injured body part was the knee with 77 injuries (27%) and 37 of these were severe. The head was the next most commonly injured body part with 39 (13%) injuries. As many as 106 injuries (36%) occurred during WC/World Ski Championship competitions, corresponding to an injury rate of 15.6 injuries per 1000 runs (95% CI, 12.7 to 18.6). There were no significant differences between men and women in either the injury rate or the rate seen for knee injuries. **Conclusions**: The injury rate among WC athletes in freestyle skiing is high, especially for severe injuries. The knee is the most commonly injured body part, also dominated by severe injuries. We found no significant difference in the injury rate related to sex.

Introduction

Freestyle skiing is a relatively recent addition to the traditional Olympic winter sports — combining speed, showmanship and the ability to perform aerial manoeuvres while skiing.[1] Today, the freestyle skiing events at the World Cup (WC) level consist of five disciplines; moguls, dual moguls, aerials, halfpipe and ski cross.

In mogul skiing, the athlete skis down a 200-250 m long course uniformly covered with moguls and also containing two jumps. In dual moguls, competitors compete head to head on parallel mogul courses. In aerials, the athletes perform high jumps where they are scored according to the difficulty of the manoeuvre performed and their execution. In halfpipe, the skiers ski down a 100-140 m long snow-constructed pipe with 3-4.5 m high walls, performing a series of manoeuvres skiing off the walls into the air, landing back into the pipe again. Ski cross has the longest course of the freestyle disciplines (900-1200 m). The skiers, in groups of four to six, race head to head past several freestyle skiing challenges (e.g. turns, jumps and waves) in several elimination heats until the final settles the podium positions.[2]

Dowling [3] monitored injuries in US Ski Association events during the 1978-1979 and 1979-1980 seasons, estimating that there were 2.8 injuries per 1000 skier-days, with knee, head and spine injuries the most frequent. However, the freestyle skiing sport has evolved considerably from the early 1980s and halfpipe and ski cross have been added as new disciplines to the WC programme.

Thus, the aim of this study was to describe the risk of injury and the injury pattern among competitive WC freestyle skiers during the competitive winter season and to examine sex and discipline as risk factors.

Material and methods

Study design and population

We conducted retrospective interviews in a cohort of WC freestyle skiers from predefined teams at the end of the 2006-2007, 2007-2008 and 2008-2009 winter seasons. A methodological study[4] comparing prospective injury reporting by team medical personnel, prospective injury reporting by International Ski Federation (FIS) technical delegates and retrospective athlete/coach interviews showed that retrospective interviews were the most accurate in this setting. We therefore chose this method to record injuries among WC freestyle skiers. We defined the winter season as starting on 1 November. We conducted the interviews at the two final events in Voss, Norway (2-3 March 2007) and Madonna di Campiglio, Italy for the first season, the final WC events in Valmalenco, Italy (12-16 March 2008) for the second season and the final WC events in La Plagne, France (18-19 March 2009) for the third season.

From the official FIS database we identified athletes who had started in at least one WC/World Ski Championship (WSC) event in moguls, dual moguls, halfpipe, aerials and ski cross. We included all athletes from the teams of Germany, Switzerland, Canada, Finland, France, Norway, Italy, Sweden and Austria for all three seasons. For the 2007-08 and 2008-09 winter season we also included complete WC teams in the different disciplines from 11 additional nations to increase the study population. Except for the 2006-07 season when halfpipe was excluded because of cancellations due to lack of snow, we interviewed athletes from all disciplines. We excluded national teams in sub-disciplines if the response rate from that particular nation was less than 80%.[5]

At the final events of the three seasons, we interviewed the athletes from the selected nations who were present in person. If any athletes were not present (due to injury or for other reasons), we interviewed their coaches. Some coaches directed us to their team physician/physical therapist in order to obtain the information required. We also asked the team coaches to control and complete the list of athletes from their nation. Athletes not defined as being on the WC team roster by the coaches were excluded (e.g. national athletes starting in races in that country on the national quota).

Research teams consisting of physicians and physical therapists from the Oslo Sports Trauma Research Center performed the interviews in the finishing area in connection with official training or competition, or, in some cases, at the team's hotel. To facilitate athlete recall of participation and time loss due to injury, we used a form outlined as the week-by-week calendar of the freestyle WC season as an interview too.[4]

The Regional Committee for Medical Research Ethics, Region Sør-Norge and the Norwegian Social Science Data Services approved the study.

Injury definition

The injury definition was "all injuries that occurred during training or competition and required attention by medical personnel". This definition, as well as the classification of the type of injury and body part injured, was based on a recent consensus document on injury surveillance in football.[6] Training included activities on snow and basic training not on snow. We classified the severity of injury according to the duration of absence from training and competition as slight (no absence); minimal (1 to 3 days), mild (4 to 7 days), moderate (8

to 28 days) and severe (>28 days).[6] For each injury recorded, the interviewer completed an injury form containing information on the body part injured, the injury type, the severity of the injury, as well as the specific diagnosis. If multiple injuries resulted from the same event, we described all of these on the same form. We also recorded information on where the injury occurred; during WC/WSC competition/official training, other competition/official training, other training activity on snow (i.e. regular training) or basic training not on snow (i.e. running, weightlifting, soccer etc.).[4]

Statistics including injury incidence and exposure

To present the most complete picture of injury risk we have expressed injury incidence as the absolute injury rate (expressed as the total number of injuries per 100 athletes per season) as well as the relative injury rate (corrected for exposure, expressed as the number of injuries per 1000 runs), both with their corresponding 95% CI. When calculating the absolute injury rate we included all injuries during the season, in competition as well as during training as described in a previous study.[4] To calculate the relative injury rate we included injuries in WC/WSC competitions only – as the number of started runs (exposure) was available from these competitions only. A jump in aerials is also referred to as a run in this study. For each of the skiers we calculated their competition exposure as the exact number of started runs during the 2006-2007, 2007-2008 and the 2008-2009 winter seasons based on information from the FIS database. The database includes information on race completion and positions. If an athlete was disqualified, we included the runs up to and including the disqualified run. For the different disciplines the average of runs per competition varied from one to five in ski cross, one to two in aerials, one to four in halfpipe, one to two in moguls and one to five in dual moguls depending on the racer's final result.

We based our calculation on the Poisson model and used a Z test for comparing injury risk between disciplines and computed the corresponding 95% CI. We computed relative risks (RR) with their 95% CI to compare injury rate between male and female athletes for severity, distribution with regards to body part injured and the relative risk between the different disciplines for all injuries and knee injuries. A two-tailed p-level of ≤ 0.05 was considered statistically significant.

Results

We interviewed 662 freestyle athletes from the teams selected for the study (426 males and 236 females) during the three winter seasons from 2006 until 2009 (Table 1). Of these, 290 interviews (44%) were done with the athletes and 372 (56%) with coaches/medical personnel. Three athletes were interviewed via telephone/e-mail within 4 weeks of the interviews. Overall, this represents a 98% response rate for athletes on the freestyle WC teams in question. During the three World Cup seasons, 93 athletes were interviewed twice and 72 athletes were interviewed in all three seasons. Only one athlete competed in more than one WC discipline and was categorised in the discipline where the lowest ranking was obtained.

Table 1. The number of athletes interviewed in the different disciplines for the three seasons in WC freestyle skiing

	2006-07		2007-08		2008-09		Sum three seasons		
Discipline	Males	Females	Males	Females	Males	Females	Males	Females	Total
Moguls/dual moguls	47	19	57	27	50	33	154	79	233
Ski cross	48	23	65	29	57	47	170	99	269
Aerials	12	4	31	16	12	13	55	33	88
Halfpipe	-	-	24	14	23	11	47	25	72
Total	107	46	177	86	142	104	426	236	662

A total of 291 acute injuries (179 among men and 112 among women) were recorded and 77 injuries (26.5%) did not lead to any time loss from training and/or competition. Of the 211 time-loss injuries, the majority were severe, with an absence of >28 days (93, 44%) or moderate (8-28 days absence) (51, 24%). There were 34 mild injuries (4-7 days, 16%) and 33 minimal injuries (1-3 days, 16%). In three cases, we did not have data on injury severity.

The number of injuries and absolute injury rate (injuries per 100 athletes per season) within the different freestyle WC disciplines are shown in Table 2. We found a higher total injury rate in the other disciplines than in moguls/dual moguls (RR ski cross vs. moguls/dual moguls: 1.49, 95% CI 1.13 to 1.98; aerials vs. moguls/dual moguls: 1.60, 95% CI 1.11 to 2.31; halfpipe vs. moguls/dual moguls: 1.62, 95% CI 1.10 to 2.39). There was also a higher injury rate for time-loss injuries in aerials and halfpipe than in moguls/dual moguls (RR aerials vs. moguls/dual moguls: 1.63, 95% CI 1.07 to 2.48; halfpipe vs. moguls/dual moguls: 1.59, 95% CI 1.01 to 2.50) and a trend for ski cross (RR ski cross vs. moguls/dual moguls: 1.38, 95% CI 0.99 to 1.93). We found no difference in the rate of severe injuries between the different disciplines. There was no sex difference in absolute injury rate in any discipline or severity category (RR women vs. men: 1.13, 95% CI 0.89 to 1.43 for all injuries, RR women vs. men: 1.08, 95% CI 0.81 to 1.43 for time-loss injuries and RR women vs. men: 1.14, 95% CI 0.75 to 1.73 for severe injuries).

Table 2. Number of injuries (N) and absolute injury rate (expressed as the number of injuries per 100 athletes per seasons) with 95% CI for all recorded injuries (n=291), time-loss injuries (≥1 day absence) and severe injuries (>28 days) for the different disciplines of moguls/dual moguls (MO/DM), ski cross (SX), aerials (AE) and halfpipe (HP).

	All injuries		Time-loss injuries (≥1 day)		Severe injuries (>28 days)	
Discipline	N	Incidence	N	Incidence	N	Incidence
MO/DM	76	32.6 (25.3 to 40.0)	57	24.5 (18.1 to 30.8)	28	12.0 (7.6 to 16.5)
SX	131	48.7 (40.4 to 57.0)	91	33.8 (26.9 to 40.8)	40	14.9 (10.3 to 19.5)
AE	46	52.3 (37.2 to 67.4)	35	39.8 (26.6 to 52.9)	14	15.9 (7.6 to 24.2)
HP	38	52.8 (36.0 to 69.6)	28	38.9 (24.5 to 53.3)	11	15.3 (6.2 to 24.3)
Total	291	44.0 (38.9 to 49.0)	211	31.9 (27.6 to 36.2)	93	14.0 (11.2 to 16.9)

Overall, 135 injuries (46.5%) were located in the lower extremity. The injury distribution is shown separately for men and women in Figure 1. The most commonly injured body part was the knee (n=77, 26.5%), and 38 (49.4%) of these were severe (Table 3). The second most frequently injured body parts were the head and face (n=39, 13.4%), where five injuries (12.8%) were severe. There was no difference in the absolute rate of severe knee injuries between men (6.8 injuries per 100 athletes per season) and women (7.9 injuries per 100 athletes per season, RR 1.15 vs. men, 95% CI 0.61 to 2.17). However, we observed a higher risk for head injuries in women compared to males (RR 2.11, 1.12 to 3.95).

Table 3. Description of all recorded injuries in freestyle skiing (n=291) with regard to body part injured (rows) and severity category (columns) classified according to the number of days' absence from training and competition.

Time loss Body part injured	No time loss	1-3 days	4-7 days	8-28 days	>28 days	Information missing	Total (%)
Head/face	6	4	10	14	5		39 (13.4)
Neck, cervical spine	2	1					3 (1.0)
Shoulder, clavicula	6	1	3	9	12	1	32 (11.0)
Upper arm					2		2 (0.7)
Elbow	3	2	2	2	1		10 (3.4)
Forearm		1			2		3 (1.0)
Wrist	1	2			4	1	8 (2.7)
Hand, finger, thumb	10	2	1	3	4		20 (6.9)
Chest (sternum,ribs,upper back)	7	4	2		3		16 (5.5)
Abdomen					1		1 (0.3)
Lower back, pelvis, sacrum	7	5	2	3	5		22 (7.6)
Hip, groin	5		3	3	7		18 (6.2)
Thigh	5		1			1	7 (2.4)
Knee	12	6	7	14	38		77 (26.5)
Lower leg, Achilles tendon	10	2		1	5		18 (6.2)
Ankle	2	3	3	2	3		13 (4.5)
Foot, heel, toe	1				1		2 (0.7)
Total (%)	77 (26.5)	33 (11.3)	34 (11.7)	51 (17.5)	93 (32.0)	3 (1.0)	291 (100)

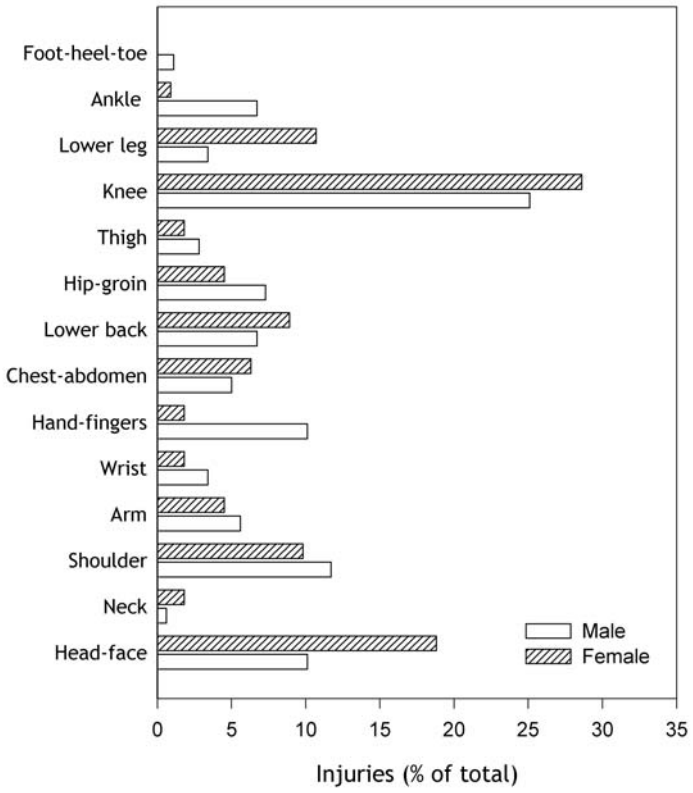

Figure 1: Distribution by body region of all reported injuries (n=291) expressed as the percentage of the total number reported for males (n=179; open bars) and females (n=112; hatched bars).

The most common injury types in freestyle skiing were joint and ligament injuries (42.6%) followed by fractures and bone stress (18.9%). As seen in Table 4, the knee accounted for 69 (55.6%) of all joint and ligament injuries and knee ligament injuries was the most frequent injury type. There were 24 anterior cruciate ligament (ACL) ruptures (63% of all severe knee injuries). We could detect no difference between women and men in the absolute rate of ACL tears (women: 5.1 injuries per 100 athletes per season, men: 2.8; RR 1.81, 95% CI 0.81 to 4.02). Of the 39 head injuries, 32 were concussions, accounting for 97% of all injuries to the nervous system. As many as 19 (59%) of the concussions were moderate or severe.

Table 4. Description of all recorded injuries (n=291) with respect to body part injured (rows) and injury type (columns)

Injury type Body part injured	Fractures and bone stress	Joint and ligament	Muscle and tendon	Contusions	Lacerations and skin lesions	Nervous system incl concussions	Other	Information not available	Total
Head/face	3				2	32	2		39 (13.4)
Neck, cervical		2	1						3 (1.0)
Shoulder, clavicle	6	15	8	3					32 (11.0)
Upper arm	1		1						2 (0.7)
Elbow	2	6		2					10 (3.4)
Forearm	3								3 (1.0)
Wrist	5	2						1	8 (2.7)
Hand, finger, thumb	12	7			1				20 (6.9)
Chest (sternum,ribs,upper back)	4	4	4	4					16 (5.5)
Abdomen							1		1 (0.3)
Lower back, pelvis, sacrum	5	5	5	6		1			22 (7.6)
Hip, groin	1	2	6	9					18 (6.2)
Thigh			6	1					7 (2.4)
Knee	4	69	4						77 (26.5)
Lower leg, Achilles tendon	7		3	7				1	18 (6.2)
Ankle	1	12							13 (4.5)
Foot, heel, toe	1			1					2 (0.7)
Total	55 (18.9)	124 (42.6)	38 (13.1)	33 (11.3)	3 (1.0)	33 (11.3)	3 (1.0)	2 (0.7)	291 (100)

Table 5 Number of all injuries (n=106) and exposure (the total number of runs, n=8734) in the different disciplines during World Cup/World Ski Championship competitions. Injury incidence is shown with 95% CI for all injuries in the different disciplines among male and female skiers as well as for knee injuries only (n=31), as well as the relative risk for males versus females. *Less than 5 cases and need to be interpreted with caution.

	Injuries (n)		**Exposure (runs)**		**Incidence (injuries per 1000 runs)**			**Relative risk**	**Knee injury incidence (injuries per 1000 runs)**			**Relative risk**
Discipline	Male	Female	Male	Female	Men	Women	Total	Men vs. women	Men	Women	Total	Men vs. women
Ski Cross	34 (11)	27 (8)	2054	1240	16.6 (11.0 to 22.1)	21.8 (13.6 to 30.0)	18.5 (13.9 to 23.2)	0.76 (0.46 to 1.26)	5.4 (2.2 to 8.5)	6.5 (2.0 to 10.9)	5.8 (3.2 to 8.4)	0.83 (0.33 to 2.06)
Moguls/Dual moguls	17 (7)	5 (2)	1477	906	11.5 (6.0 to 17.0)	5.5 (0.7 to 10.4)	9.2 (5.4 to 13.1)	2.09 (0.77 to 5.65)	4.7 (1.2 to 8.3)	2.2* (0 to 5.3)	3.8 (1.3 to 6.2)	2.15 (0.45 to 10.3)
Halfpipe	8 (1)	2 (0)	258	161	31.0 (9.5 to 52.5)	12.4* (0 to 29.6)	23.9 (9.1 to 38.7)	2.50 (0.53 to 11.8)	3.9* (0 to 11.5)	0*	2.4* (0 to 7.1)	-
Aerials	7(1)	6 (1)	405	273	17.3 (4.5 to 30.1)	22.0 (4.4 to 39.6)	19.2 (8.8 to 29.6)	0.79 (0.26 to 2.34)	2.5* (0 to 7.3)	3.7 (0 to 10.8)	2.9* (0 to 7.0)	0.67 (0.04 to 10.8)
Total	66 (20)	40 (11)	4194	2580	15.7 (11.9 to 19.5)	15.5 (10.7 to 20.3)	15.6 (12.7 to 18.6)	1.02 (0.69 to 1.50)	4.8 (2.7 to 6.9)	4.3 (1.7 to 6.8)	4.6 (3.0 to 6.2)	1.10 (0.54 to 2.33)

Of the 291 injuries, 106 (36.4%) occurred during WC/WSC competitions, 74 (25.4%) during official training for these competitions, while 59 (20.3%) injuries resulted from regular training on snow. Four injuries (1.4%) occurred during basic training (not on snow) and the rest (48, 16.5%) during other competitions. Based on the FIS database we estimated the total exposure during WC/WSC competitions for the athletes interviewed to 6774 runs (Table 5) and the relative injury rate could be estimated for the 106 injuries which occurred during these events. Of these, 72 lead to time loss from training/competition, corresponding to a relative rate of 10.6 (95% CI 8.2 to 13.1) time-loss injuries per 1000 runs. The relative injury rate across the different disciplines for all injuries (n=106) as well as knee injuries (n=31) is shown for men and women in Table 5. Compared with moguls/dual moguls, the other disciplines had a higher injury rate (RR ski cross vs. moguls/dual moguls: 2.00, 95% CI 1.23 to 3.27; RR aerials vs. moguls/dual moguls: 2.08, 95% CI 1.05 to 4.12; RR halfpipe vs. moguls/dual moguls: 2.59, 95% CI 1.22 to 5.46). There was no significant difference in the relative rate of injury or knee injury between men and women in any of the disciplines, but it should be noted that in some disciplines there were less than 5 cases and the results therefore must be interpreted with caution.

Discussion

This is the first cohort study to examine the overall injury risk and detailed injury pattern among WC freestyle skiers during the competitive season. The main findings were that the injury rate was high, especially for severe injuries and knee injuries. We observed no difference in the absolute or relative injury rate between male and female skiers.

However, there are some limitations that must be borne in mind when interpreting the results. We have reported all injuries occurring during three consecutive WC seasons based on

retrospective interviews with athletes, and, in more than half of the cases, with their coaches. Recall bias is a challenge with retrospective interviews. However, a methodological study found this to be the best method available to record injuries among WC skiers and snowboarders.[4] A freestyle skiing team is a small and close-knit community where each coach is responsible for a small number of athletes, travelling and living together during the entire WC season. In contrast, the team doctor and physiotherapist rarely travel with the team. It is therefore not surprising that the capture rate is much higher when interviewing the athlete or coach. Injuries occurring while on tour are not always seen by team medical staff. The same methodological study also found a good to very good agreement for body part injured and injury type between retrospective athlete interviews and prospective injury recording by medical team personnel.[4] Nevertheless, when using interviews with non-medical persons, it may be a challenge to obtain the correct specific diagnosis. Another limitation is that the injuries recorded in this study were from the WC season only; we do not know what occurs during training the rest of the year. Also when looking at the injury incidence for the different disciplines, the number of knee injuries was limited in some of the disciplines and the results therefore must be interpreted with caution.

Injury incidence

We have estimated the injury rate in two different ways; as the absolute rate (the injury risk per season) and the relative rate (the injury risk per run). However, the relative injury rate could only be estimated for injuries in WC/WSC competitions, where we could extract a complete record from the FIS database of the exact number of runs for each of the athletes interviewed. We found that the absolute injury rate for mogul/dual mogul skiers was lower compared to the other disciplines for all injuries. There was, however, no significant difference in the absolute injury rate between the different disciplines for the most severe

injuries. For injuries during WC/WSC competitions, we also found that mogul/dual moguls had the lowest injury rate compared to the other disciplines. The freestyle disciplines are diverse. Ski cross features the longest course and occasional body contact between the four to six skiers, who face a number of challenging freestyle elements. In halfpipe and aerials the course is shorter, but with difficult manoeuvres and spectacular jumps. When the relative injury rate between these disciplines is compared, these differences need to be noted. Nevertheless, the number of injuries per 1000 runs is the exposure estimate most frequently used for elite skiers and snowboarders.[7-9] There is only previous study available from freestyle skiing, reporting on injuries in US Ski Association freestyle competitions from 1976 to 1980.[3] This reported the number of injuries per 1000 skier days for practice and competitions, the most common measure used for recreational skiing. Considering the many changes that have taken place since the 1970s, including the addition of ski cross and halfpipe as new disciplines (and the removal of ballet), a direct comparison is difficult. Nevertheless, their finding of a lower injury rate in mogul events compared to aerial events is confirmed in our study. No previous study has described the injury rate for ski cross and halfpipe. However, if we compare to WC alpine skiing, the injury rate in ski cross, halfpipe and aerials (ranging from 18.5 to 23.9 injuries per 1000 runs in the current study) seems to be at least as high as that reported from downhill skiing (the highest among the alpine skiing disciplines with 17.2 injuries per 1000 runs).[10] One similarity with alpine skiing is that the majority of the reported freestyle injuries were severe, leading to a time loss from training and competition of >28 days. This is in contrast to most other sports, where severe injuries are the least frequent. Considering the challenging manoeuvres executed in each of the freestyle disciplines, the high frequency of severe injuries may not come as a surprise. However, the data show that research is needed to understand the injury mechanisms and develop appropriate preventive measures.

Knee injuries

Previous studies have shown that the knee is the most commonly injured body part among World Cup alpine skiers, as well as adult recreational skiers.[10-14] The same pattern was seen in elite freestyle skiers in the late 1970s; knee injuries were the most frequent, followed by injuries to head and spine.[3] Our results confirm that the knee is the most commonly injured body part in freestyle skiing, accounting for one-fourth of all injuries. The ACL was involved in at least 38% of these; however, this probably represents a minimum estimate, as not all athletes/coaches could give a precise diagnosis. Nevertheless, our findings are supported by Heir and co-workers,[15] who showed that 47% of the 95 participants in the FIS Freestyle World Championship in 2001 had experienced at least one major knee injury with an absence of at least 20 days. One-fourth of the skiers in the same study reported to have suffered at least one previous ACL injury.

Whether the injury mechanisms in World Cup freestyle skiing are the same as those described to cause ACL injuries in recreational alpine skiing [16-21] is unknown. The numbers (and thus the statistical power) become small when we divide the knee injuries into the different disciplines, but it seems that the risk for knee injuries is high across all disciplines. Whether injuries result from landing after a jump, resembling the boot-induced anterior drawer mechanism with deep knee flexion described to be common among high-level alpine skiers,[16] or occur when the skier is off balance in the mogul course or are due to collisions/crashes in ski cross needs to be investigated. According to the FIS freestyle competition rules,[2] bindings must be of a recognized release system meeting international standards for all the disciplines. Heir and co-workers[22] found that freestyle WC skiers tighten their bindings to values well above the recommended standards. Although studies

from recreational skiing have shown that well-adjusted release bindings have reduced the risk of lower leg injuries,[23-25] they have not prevented knee sprains.[25]

Head injuries

Although helmet use is compulsory in all freestyle disciplines in the FIS WC and we would expect that athletes at this level use helmets also for training and in other competitions, we found head injuries to be frequent. Most of these were concussions and as many as 53% were moderate to severe. A reduction in the risk of head injuries of between 29% and 60% has been reported with the use of helmets. [26,27] Mecham and co-workers[28] looked at head impacts to freestyle aerial skiers and found that slapback events were common. These occur when the skier over-rotates in the air, resulting in a rotation backwards after the ski tails contact the snow and then the back and head impact the landing surface. Through more detailed information on the energy transfer it may be possible to develop helmets specifically for freestyle skiing.

Sex differences

In recreational alpine skiing, some studies have shown the total injury rate to be unrelated to sex,[11,24] while some specific injury types seem to be more common among either men or women. A recent study from WC alpine skiing has shown that the overall injury risk and the injury incidence in WC/WSC competitions were twice as high in males compared to females.[10] In contrast, the present data on freestyle skiing show no sex difference in the absolute or relative injury risk. Several studies have reported a twofold greater rate of knee injuries among female recreational skiers,[14,29-31] while the rate of shoulder, spine and head injuries has been shown to be higher rate in male skiers.[14,29,32-34] However, no sex differences were found in the rate of knee injuries among World Cup alpine skiers.[10] Heir and co-workers [15] found, among 95 freestyle competitors at the FIS World Championship

(2001), that the prevalence of previous, major knee injuries was significantly higher in women than men, but there was no significant difference in the prevalence of former ACL injuries or any other specific knee injuries between male and female skiers. Although we observed a higher risk for head injuries in women, we could not detect any sex difference in the absolute or relative knee injury rate or between the different disciplines. This corroborates the findings from WC alpine skiing, but is in contrast to team sports such as team handball and soccer,[10,35-37] where women have a four- to sixfold higher rate of non-contact ACL injuries. As noted for alpine skiing, perhaps the technical demands and forces involved in freestyle skiing overrule any vulnerability factors related to sex.

WHAT IS ALREADY KNOWN ON THIS TOPIC

- There are no recent data from large cohort studies on the injury risk and pattern among elite freestyle skiers.

WHAT THIS STUDY ADDS

- The injury rate among World Cup freestyle skiers during the competitive season is high, particularly for severe injuries
- Knee injuries are common, followed by head injuries
- There is no difference in the overall injury risk or risk for knee injuries between male and female skiers

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References

(1) Olympic Movement. Freestyle skiing Equipment and history. www.olympic.org/en/content/Sports/All-Sports/Skiing/Freestyle-Skiing/Freestyle-skiing-Equipment-and-history/ (Accessed October 2009)

(2) International Ski Federation. FIS International freestyle competition rules. www.fis-ski.com/data/document/icr-08-freestyle-print-version.pdf (Accessed September 2009)

(3) Dowling PA. Prospective study of injuries in United States Ski Association freestyle skiing--1976-77 to 1979-80. *Am J Sports Med* 1982;10(5):268-75.

(4) Flørenes TW, Nordsletten L, Heir S, et al. Recording injuries among World Cup skiers and snowboarders: a methodological study. *Scand J Med Sci Sports* Published Online First 18 December 2009. doi: 10.1111/j.1600-0838.2009.01048.x

(5) Flørenes TW, Nordsletten L, Heir S, et al. Injuries among World Cup ski and snowboard athletes. *Scand J Med Sci Sports* 2010;Accepted.

(6) Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Br J Sports Med* 2006;40(3):193-201.

(7) Bergstrom KA, Bergstrom A, Ekeland A. Organisation of safety measures in an Alpine World Junior Championship. *Br J Sports Med* 2001;35(5):321-4.

(8) Ekeland A, Dimmen S, Lystad H, et al. Completion rates and injuries in alpine races during the 1994 Olympic Winter Games. *Scand J Med Sci Sports* 1996;6(5):287-90.

(9) Torjussen J, Bahr R. Injuries among elite snowboarders (FIS Snowboard World Cup). *Br J Sports Med* 2006;40(3):230-4.

(10) Flørenes TW, Bere T, Nordsletten L, et al. Injuries among male and female World Cup alpine skiers. *Br J Sports Med* 2009;43(13):973-8.

(11) Davidson TM, Laliotis AT. Alpine skiing injuries. A nine-year study. *West J Med* 1996;164(4):310-4.

(12) Sutherland AG, Holmes JD, Myers S. Differing injury patterns in snowboarding and alpine skiing. *Injury* 1996;27(6):423-5.

(13) Langran M, Selvaraj S. Snow sports injuries in Scotland: a case-control study. *Br J Sports Med* 2002;36(2):135-40.

(14) Ekeland A, Rødven A. Injuries in Norwegian Ski Resorts the Winter Seasons of 2005 and 2006. *Journal of American Society for Testing and Materials International* 2009;5:43-8.

(15) Heir S, Krosshaug T, Ekeland A. The Prevalence of Previous Serious Knee Injuries in Freestyle World Championship Skiers. In: Johnson RJ, ed. Skiing Trauma and Safety: Fourteenth Volume, ASTM STP 1440. ASTM International, West Conshohocken, PA, 2003 2003.

(16) Johnson RJ. Prevention of cruciate ligament injuries. In: Feagin JrJA, ed. The crucial ligaments. Churchill Livingstone, New York 1988: 349-56.

(17) Johnson RJ, Renstrom PAFH. Injuries in Alpine Skiing. In: Renstrom PAFH, ed. Clinical Practice of Sports Injury Prevention and Care. Blackwell Scientific Publications 1994: 676-98.

(18) Jarvinen M, Natri A, Laurila S, et al. Mechanisms of anterior cruciate ligament ruptures in skiing. *Knee Surg Sports Traumatol Arthrosc* 1994;2(4):224-8.

(19) Ekeland A, Thoresen BO. Isolated rupture of the anterior cruciate ligament by knee hyperflexion. In: Mote JrCD, Johnson RJ, eds. Skiing Trauma and Safety: Sixth International Symposium. American Society for Testing and Materials, Philadelphia, ASTM STP 938 1987: 61-7.

(20) McConkey JP. Anterior cruciate ligament rupture in skiing. A new mechanism of injury. *Am J Sports Med* 1986;14(2):160-4.

(21) Ettlinger CF, Johnson RJ, Shealy JE. A method to help reduce the risk of serious knee sprains incurred in alpine skiing. *Am J Sports Med* 1995;23(5):531-7.

(22) Heir S, Dimmen S, Ekeland A. On-slope evaluation of release bindings for World Cup Freestyle skiers. In: Johnson RJ, Zucco P, Shealy JE, eds. Skiing trauma and safety: thirteenth volume, ASTM STP 1397. West Conshohocken, PA, USA: American Society for Testing and Materials, 2000:3-10.

(23) Johnson RJ, Ettlinger CF, Shealy JE. Update on Injury Trends in Alpine Skiing. In: Johnson RJ, Zucco P, Shealy JE, eds. Skiing Trauma and Safety: Thirteenth Volume, ASTM STP 1397. American Society for Testing and Materials, West Conshohocken, PA 2000: 108-18.

(24) Ekeland A, Sulheim S, Rødven A. Injury rates and Injury Types in Alpine Skiing, Telemarking, and Snowboarding. In: Johnson RJ, Shealy JE, Ahlbäumer MG, eds. Skiing Trauma and Safety: Fifteenth Volume, ASTM STP 1464. American Society for Testing and Materials, West Conshohocken 2005: 31-9.

(25) Ettlinger CF, Johnson RJ, Shealy J. Functional and Release Characteristics of Alpine Ski. In: Johnson RJ, Shealy JE, Yamagishi T, eds. Skiing Trauma and Safety 16th Volume, ASTM STP 1474. American society for testing and materials international, West Conshohocken 2006: 65-74.

(26) Hagel BE, Pless IB, Goulet C, et al. Effectiveness of helmets in skiers and snowboarders: case-control and case crossover study. *BMJ* 2005;330(7486):281.

(27) Sulheim S, Holme I, Ekeland A, et al. Helmet use and risk of head injuries in alpine skiers and snowboarders. *JAMA* 2006;295(8):919-24.

(28) Mecham MD, Greenwald RM, Macintyre JG, et al. Incidence and severity of head impact during freestyle aerial ski jumping. *Journal of Applied Biomechanics* 1999;15:27-35.

(29) Greenwald RM, France EP, Rosenberg TD, Toelcke T. Significant Gender Differences in Alpine Skiing Injuries: A Five-Year Study. In: Mote JrCD, Johnson RJ, Hauser W, Schaff PS, eds. Skiing Trauma and Safety: Tenth Volume, ASTM STP 1266. American Society for Testing and Materials 1996: 36-44.

(30) Shealy JE, Ettlinger CF. Gender-Related Injury Patterns in Skiing. In: Mote JrCD, Johnson RJ, Hauser W, Schaff PS, eds. Skiing Trauma and Safety: Tenth Volume, ASTM STP 1266. American Society for Testing and Materials, 1996 1996: 45-57.

(31) Laporte J-D, Binet M-H, Constans D. Evolution of ACL Ruptures in French Ski Resorts 1992-1999. In: Johnson RJ, Zucco P, Shealy JE, eds. Skiing Trauma and Safety: Thirteenth Volume, ASTM STP 1397. American Society for Testing and Materials, West Conshohocken, PA 2000: 95-107.

(32) Tarazi F, Dvorak MF, Wing PC. Spinal injuries in skiers and snowboarders. *Am J Sports Med* 1999;27(2):177-80.

(33) Levy AS, Hawkes AP, Hemminger LM, et al. An analysis of head injuries among skiers and snowboarders. *J Trauma* 2002;53(4):695-704.

(34) Floyd T. Alpine skiing, snowboarding, and spinal trauma. *Arch Orthop Trauma Surg* 2001;121(8):433-6.

(35) Myklebust G, Maehlum S, Holm I, et al. A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. *Scand J Med Sci Sports* 1998;8(3):149-53.

(36) Agel J, Arendt EA, Bershadsky B. Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer: a 13-year review. *Am J Sports Med* 2005;33(4):524-30.

(37) Faude O, Junge A, Kindermann W, et al. Injuries in female soccer players: a prospective study in the German national league. *Am J Sports Med* 2005;33(11):1694-700.