



Factors associated with self-reported failure of binding to release among recreational skiers: an epidemiological study

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ABSTRACT

Female recreational skiers have twice the knee injury incidence of male skiers and the reported proportion of failure of binding release is considerably higher among females. It remains unclear whether this sex difference belongs only to an injury of the knee joint or also to other body parts. Therefore, the aim of the study was to evaluate factors associated with failure of binding release among a cohort of injured male and female recreational skiers. In total, 1369 injured skiers (43.1 % females) were interviewed on sex, age, date of last binding adjustment, skill level, risk taking behaviour and injured body part and binding release at the moment of accident. Failure of binding release was reported within 39.9 % of all cases at the moment of the accident. An actual binding adjustment was significantly associated with a decreasing proportion of failure of binding release. Failure of binding release was significantly higher for females compared to males (51 vs. 32 %) and for cautious compared to risky skiers (42 vs. 33 %) while sexes did not differ regarding the date of the last binding adjustment. Regarding knee injuries, female skiers showed a higher proportion of failure of binding release compared to male skiers (61 vs. 46 %) with an OR of 1.8 (95 % CI, 1.2-2.8). Consequently, failure of binding release was significantly more frequent in females compared to males, irrespective of the injured body part although sexes did not differ with regard to the date of the last binding adjustment.

Keywords:

alpine skiing – ski injury – ski bindings – binding settings

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Introduction

Alpine skiing is one of the most popular winter recreational sports annually enjoyed by several hundred million people worldwide (Russel, Christie, & Hagel, 2010). The most common accident causes on ski slopes are self-inflicted falls with 80-90 % and collisions with other persons with about 10-15 %, respectively (Ekeland & Rodven, 2011; Ruedl, Kopp, Sommersacher, Woldrich, & Burtscher, 2013). The most common anatomical location of an injury in recreational alpine skiing is the knee joint with about one third of all injuries in male and female ski-

ers (Burtscher et al., 2008; Ekeland & Rodven, 2011; Kim, Endres, Johnson, Ettlinger, & Shealy, 2012). The anterior cruciate ligament (ACL) is injured in about 15-21 % of all skiing injuries in adult recreational skiers (Kim et al., 2012; LaPorte, Bajolle, Lamy & Delay, 2012). Interestingly, there are decisive sex differences in rates of knee injuries. Female recreational skiers have twice the knee injury incidence of male skiers and the ACL injury risk is three times greater in female skiers (Beynon, Ettlinger & Johnson, 2007; Burtscher et al., 2008; Ekeland & Rodven, 2011). This sex difference may be partly related to hormonal, anatomical and neuromuscular risk factors which distinguish males from

females (Hewett, Meyer, & Ford, 2006). In alpine skiing, mainly knee injuries are associated with a high amount of failure of binding releases, however, again with a decisive sex difference (Greenwald & Toelcke, 1997; LaPorte, Binet, Fenet, Constans, & Joubert, 2008; Ruedl et al., 2011). Studies (Greenwald & Toelcke, 1997; LaPorte et al., 2008; Ruedl et al., 2011) found that female recreational skiers with a knee injury reported in 74-88 % failure of binding release at the moment of accident compared to male skiers with 55-67 %.

Current ski bindings are mostly designed to release during a simple forward fall (upward release function of the heel piece) or during a forward fall with body rotation (side release function of the toe piece of the ski binding) (Hull, 1997). Therefore, it could be speculated that compared to males the higher number of failure of binding release among female skiers with a knee injury was due to a possibly higher number of backward falls in which cases most ski bindings are not able to release. However, a recent study by Ruedl et al. (2016) showed an equal distribution of different types of forward and backward falls among a cohort of 160 male and 337 female skiers with an ACL injury refuting the above mentioned hypothesis.

In general, injuries on ski slopes are likely to be the result of a complex interaction of intrinsic risk factors including age, sex, skill level, risk taking behaviour etc. and extrinsic risk factors including the environment and the equipment, e.g. time of binding adjustment (Bahr & Krosshaug, 2005; Burtscher, Sommersacher, Ruedl & Nachbauer, 2009; Sulheim, Holme, Rodven, Ekeland & Bahr, 2011). Burtscher et al. (2008) found that female skiers not using newly adjusted bindings had a higher risk of knee injury than those with newly adjusted bindings. To date, release values of the bindings according to the ISO 11088 standard (ISO 2013), however, were selected mainly using the weight of the skiers without considering other sex specific differences.

To our knowledge, most studies on failure of ski binding release are related to knee injuries and no study yet investigated the sex-specific amount of failure of binding release also among other anatomical body locations. Therefore, the aim of this study was to evaluate factors associated with failure of binding release among a cohort of injured male and female recreational skiers.

Methods

Data collection procedures

During the 2011/2012 winter season, injured skiers were interviewed about causes and potential risk factors in all 5 hospitals with an emergency department of a Western Austrian province. Injury was defined as trauma due to a fall or a collision with another skier or an object requiring hospital admission. Patients were interviewed at the same or the following day of injury. Interviews were conducted in German or English on a daily basis from 8 o'clock in the morning to 8 o'clock in the eve-

ning from December 15, 2011 until April 15, 2012. If a child was injured, parents were interviewed about the injury cause. Approximately 70 % of all injured skiers treated in the hospitals were recorded and less than 5 % refused to participate. Only alpine skiers who suffered from an injury after a self-inflicted fall without involvement of other winter sport participants have been included in this study.

Interviewers asked a total of 52 questions which were used for the most part in previous published studies (Ekeland & Rodven, 2011; Ruedl, Abart, Ledochowski, Burtscher & Kopp, 2012; Ruedl, Kopp, Sommersacher, et al., 2013; Sulheim, Ekeland & Bahr, 2007). The questions used for this study included sex, age, skill level according to Sulheim et al. (2007), risk taking behaviour (more risky vs. more cautious) according to Ruedl et al. (2012), the date of the last binding adjustment (this season, last season, before) and whether the bindings were adjusted by a professional or by one self or they did not know, binding release at the moment of accident (yes, no) and injured body parts (ankle, lower leg, knee, thigh, hip/pelvis, abdomen/chest, shoulder/back, arm, head/neck, others). Regarding skill level, people were divided into more skilled (advanced and experts) and into less skilled (beginner and intermediates) skiers as a tendency was observed to underestimate individual skiing ability (Sulheim et al., 2007).

This study was performed in conformity with the ethical standards laid down in the 2008 Declaration of Helsinki. Injured skiers gave their informed consent for the interview. In addition, the retrospective data analysis of this study was approved by the Institutional Review Board Sport Science, University of Innsbruck. Parts of this data set were also used in previously published articles (Ruedl et al., 2015; Ruedl, Bauer, et al., 2013; Ruedl, Kopp, Burtscher, Bauer & Benedetto, 2013).

Statistics

Data are presented as means and absolute and relative frequencies. Differences in mean age of injured skiers with regard to binding release were evaluated by Mann-Whitney-U tests. Injured body parts were binary coded. Differences in frequencies were evaluated by chi-square-tests. A univariate odds ratio (OR) with 95 % confidence interval (CI) was calculated to evaluate the association between sexes and failure of binding release among knee injured skiers. All P-values were two-tailed and values less than 0.05 were considered statistically significant.

Results

In total, 1369 persons (56.9 % males, 43.1 % females) with a mean age of 35.8 ± 19.2 (range 3-79) years met the inclusion criteria. During the current season 67.4 % performed the last binding adjustment, 24.6 % during the last season, and 8% before the last season. More than 90 % of ski bindings were adjusted by a professional and about 7 % by the skier himself/her-

self. The most common injured body parts among this cohort of alpine skiers were the knee (28.5 %), shoulder/back (19.2 %), arms (17.0 %), lower legs (14.4 %), and head/neck (7.1 %). Failure of binding release was reported within 39.9 % of cases at the moment of the accident.

In Table 1 characteristics of factors associated with self-reported failure of binding release among injured skiers are shown. Failure of binding release was significantly higher for females

compared to males (51 vs. 32 %) and for cautious people compared to risky people (42 vs. 33 %). An actual binding adjustment was significantly associated with a decreasing proportion of failure of binding release. Regarding injured body parts, failure of binding release was significantly higher in knee injured (55 %) and significantly lower in shoulder/back (25%) and head/neck injured (21 %) skiers (Table 1).

Table 1: Characteristics of factors associated with failure of binding release among 1369 injured skiers

	Failure of binding release	Release of binding	P-value
Age (years, mean \pm SD)	36.4 \pm 19.3	35.5 \pm 19.1	.518
Sex (%)			
Male, <i>N</i> = 776	31.6	68.4	
Female, <i>N</i> = 587	51.3	48.7	<.001
Date of last binding adjustment (%)			
This season, <i>N</i> = 741	37.1	62.9	
Last season, <i>N</i> = 271	42.8	57.2	
Before, <i>N</i> = 88	48.9	51.2	.044
Adjustment of bindings (%)			
by a professional, <i>N</i> = 1008	39.4	60.6	
by one self, <i>N</i> = 82	41.4	58.5	
did not know, <i>N</i> = 13	38.5	61.5	.931
Skill level (%)			
More skilled, <i>N</i> = 1037	38.6	61.4	
Less skilled, <i>N</i> = 323	43.3	56.7	.134
Risk taking behaviour (%)			
More risky, <i>N</i> = 324	33.3	66.7	
More cautious, <i>N</i> = 1033	41.9	58.1	.006
Injured body part (%)			
Ankle, <i>N</i> = 48	43.8	56.3	.653
Lower leg, <i>N</i> = 197	40.6	59.4	.875
Knee, <i>N</i> = 389	55.0	45.0	<.001
Thigh, <i>N</i> = 56	51.8	48.2	.064
Hip/pelvis, <i>N</i> = 38	47.4	52.6	.401
Abdomen/chest, <i>N</i> = 37	29.7	70.3	.200
Shoulder/back, <i>N</i> = 262	25.2	74.8	<.001
Arm, <i>N</i> = 232	35.3	64.7	.123
Head/neck, <i>N</i> = 97	20.6	79.4	<.001
Others, <i>N</i> = 10	40.0	60.0	.995

Table 2 shows a sex-comparison of factors investigated for this study. Significant differences were found with regard to age, failure of binding release, skill level, and risk taking behaviour. In addition, female skiers suffered significantly more often from a knee injury (39 vs. 21 %) and less often from an abdomen/chest (1 vs. 4 %), a shoulder/back (14 vs. 23 %) and an arm injury (15 vs. 19 %) than male skiers.

In Table 3 sex-specific factors associated with failure of binding release are presented. The date of last binding adjustment shows only for male skiers a significant association with the proportion of failure of binding release. Regarding injured

body parts, among males a significant difference between failure of binding release and release of bindings was found for the knee (46 vs. 54 %), shoulder/back (22 vs. 78 %) and head/neck (13 vs. 87 %) injuries. Female skiers showed a significant difference between failure of release and release of bindings within knee (61 vs. 39 %), thigh (78 vs. 22 %), and shoulder/back (33 vs. 67 %) injuries. With regard to knee injuries, female skiers showed a higher proportion of failure of binding release compared to male skiers (61 vs. 46 %) with an OR of 1.8 (95 % CI, 1.2-2.8).

Table 2: Characteristics of factors associated with injuries among male and female skiers

	Males (N=776)	Females (N=587)	P-value
Age (years, mean \pm SD)	34.8 \pm 19.6	37.1 \pm 18.6	.040
Failure of binding release (%)	31.6	51.3	<.001
Date of last binding adjustment (%)			
This season	69.5	64.5	
Last season	22.8	27.1	
Before	7.8	8.4	.211
Adjustment of bindings (%)			
by a professional	89.7	93.5	
by one self	9.0	5.4	
did not know	1.3	1.1	.072
Skill level (%)			
More skilled	79.9	71.4	
Less skilled	20.1	28.6	<.001
Risk taking behaviour (%)			
More risky	32.6	12.4	
More cautious	67.4	87.6	<.001
Injured body part (%)			
Ankle	3.6	3.4	.883
Lower leg	14.3	14.3	.995
Knee	20.6	39.0	<.001
Thigh	4.3	3.9	.785
Hip/pelvis	2.6	3.1	.621
Abdomen/chest	3.7	1.4	.007
Shoulder/back	23.1	14.0	<.001
Arm	18.8	14.5	.035
Head/neck	8.1	5.8	.110
Others	0.8	0.7	.843

Table 3: Sex-specific characteristics of factors associated with failure of binding release among male and female injured skiers

	Males (N = 776)			Females (N = 587)		
	Failure of binding release	Release of binding	P-value	Failure of binding release	Release of binding	P-value
Age (years, mean \pm SD)	33.8 \pm 20.1	35.3 \pm 19.3	.225	38.5 \pm 18.5	35.6 \pm 18.6	.108
Date of last binding adjustment (%)						
This season	29.2	70.8		49.3	50.7	
Last season	35.4	64.6		52.0	48.0	
Before	44.9	55.1	.046	53.8	46.2	.799
Adjustment of bindings (%)						
by a professional	31.2	68.8		50.6	49.4	
by one self	38.6	61.4		48.0	52.0	
did not know	25.0	75.0	.479	60.0	40.0	.885
Skill level (%)						
More skilled	30.8	69.2		50.5	49.5	
Less skilled	34.2	65.8	.440	52.1	47.9	.783
Risk taking behaviour (%)						
More risky	30.7	69.3		43.1	56.9	
More cautious	32.0	68.0	.741	52.4	47.6	.166
Injured body part (%)						
Ankle	39.3	60.7	.408	50.0	50.0	.907
Lower leg	36.0	64.0	.271	47.6	52.4	.482
Knee	46.3	53.8	<.001	61.1	38.9	<.001
Thigh	33.3	66.7	.849	78.3	21.7	.010
Hip/pelvis	35.0	65.0	.808	61.1	38.9	.476
Abdomen/chest	27.6	72.4	.839	37.5	62.5	.495
Shoulder/back	21.8	78.2	.001	32.9	67.1	<.001
Arm	29.5	70.5	.621	45.9	54.1	.293
Head/neck	12.7	87.3	.001	35.3	64.7	.076
Others	50.0	50.0	.386	25.0	75.0	.361

Discussion

The aim of this study was to evaluate factors associated with failure of binding release among a cohort of injured male and female recreational skiers. Main results showed that female sex, a not newly adjusted binding, a more cautious behaviour and knee injuries were significantly associated with failure of binding release. Regarding knee injuries, female skiers had an

about twofold higher odds ratio of failure of binding release compared to male skiers.

Mean age, sex proportion and distribution of the most common anatomical locations of injury in this study are well in accordance with other studies among recreational alpine skiers (Burtcher et al., 2008; Ruedl et al., 2013; Sulheim et al., 2011). Also, sex differences with regard to age, failure of binding release, skill level, self-reported risk taking behaviour and the

distribution of knee as well shoulder/back injuries are in accordance with ski-specific literature (Burtscher et al., 2008, 2009; Greenwald & Toelcke, 1997; LaPorte et al., 2008; Ruedl et al., 2012).

While in the present study every second injured female skier reported a failure of binding release at the moment of accident, this was true for only one third of male skiers. With regard to knee injuries, female skiers showed a considerably higher proportion (~15 %) of failure of binding release compared to male skiers. In accordance, studies on ACL injuries also reported a higher number (up to 20 %) of failure of binding release in female compared to male skiers (Greenwald & Toelcke, 1997; LaPorte et al., 2008; Ruedl et al., 2011, 2016). This difference seems not be due to a different distribution of forward and backward falls among male and female skiers (Ruedl et al., 2011, 2016).

Based on the findings by Burtscher et al. (2008) injured skiers in this study were asked about the date of the last binding adjustment. About two third of skiers reported a binding adjustment in the actual season being well in accordance with studies on ACL injuries among male and female skiers (Ruedl et al., 2011, 2016). Also according to our results, other studies (Ruedl, Pocco, et al., 2010; Ruedl et al., 2011) found no sex differences concerning the date of the last binding adjustment. Therefore, it seems unlikely that the higher proportion of female failure of binding release is due to differences in the date of binding adjustment. As more than 90 % of injured skiers reported that their ski bindings were adjusted by a professional, we assume correct binding settings according to the ISO 11088 in most of these skiers. Our results revealed for the total cohort that newly adjusted bindings seem to be associated with a higher proportion for binding release however, conducting a sex-specific analysis this association was only found for males.

To date, release values of the ski bindings according to the ISO 11088 standard were selected using the age, height, weight, self-estimated skiing style, and sole length of ski boots of the skiers without considering other sex-specific differences. A study by Ruedl et al. (2010) electronically measuring release values of ski bindings among a cohort of 172 uninjured male and female recreational skiers revealed no sex differences regarding deviations from recommended z-values according the ISO 11088 standard. Therefore, it seems unlikely that the higher proportion of failure of binding release among injured female skiers is due to sex differences among not correctly adjusted ski bindings. However, a study by Werner and Willis (2002) found that muscle strength was highly correlated with the ability to release the binding in a self-release test. The weight-to-strength ratio, however, is negatively influenced by the higher fat mass in females (Sinning, 1985) maybe partly explaining the sex difference in the lack of binding release due to less muscular strength among females.

Mean age and skill level did not influence failure of binding release in this study while more risky skiers showed a lower proportion of failure of binding release than more cautious skiers. A study by Ruedl et al. (2010) measuring speeds on ski slopes with a radar speed gun found that self-reported risk-taking ski-

ers run on average 8 km/h faster compared to cautious skiers (53 vs. 45 km/h). In addition, risk-taking behaviour in the study by Ruedl et al. (2010) was associated with younger age, higher skill level and male sex.

According to the ISO 11088 standard (International Organization for Standardization, 2013) for binding values, skiers have to differ between slow to moderate and fast skiing speed to determine their type of skiing style. However, studies (Ruedl, Sommersacher, et al., 2010; Shealy, Ettlinger, Johnson, 2005) reported that males ski significantly faster by on average 7 km/h than females on alpine ski slopes. In addition, in a recent study by Brunner et al. (2015) skiers graded their actual speed measured with a radar speed gun as fast, moderate or slow. Brunner, Ruedl, Kopp, and Burtscher (2015) found that females who classified their actual speed as "fast" skied on average 8 km/h slower than "fast" male skiers (48 vs. 56 km/h) while the average sex differences for moderate and slow skiers were about 11 km/h and 6 km/h, respectively (Brunner et al., 2015). These results clearly demonstrate that the perception of skiing speed depends on sex. Therefore, one could speculate that compared to a "slow to moderate" or "fast" skiing male the binding setting for a "slow to moderate" or "fast" skiing female might be too high as existing sex differences on actual skiing speed and speed perception have not been considered. Also, LaPorte et al. (2008) pointed out the problem of ski binding release at low speed. It seems likely that a ski binding adjusted according to the ISO 11088 standard easier release in their normal range during an on average higher speed compared to the mean speed usually run by female skiers. Therefore, one could speculate whether lower binding release values for female skiers would be meaningful to prevent or at least to diminish the prevalence of knee injuries. The importance of binding setting in female skiers has been discussed by LaPorte et al. (2006; 2008). In a case-control study, they found that lower binding release values in female skiers set 15 % lower than those recommended by the ISO 11088 standard would clearly reduce knee injuries in these persons (LaPorte et al., 2008). However, these findings mean an association, and not definitely a "cause and effect" relationship, because another study at the same time showed a decrease in ACL injury risk without reducing binding settings (Ettlinger, Johnson & Shealy, 2006) which might be partly due to the introduction of the short and shaped carving skis (Ruedl et al., 2011).

Summing up, actual binding settings according to the ISO 11088 standard do not include a sex-related factor although females are skiing at lower mean speeds (Brunner et al., 2015; Ruedl et al., 2010; Shealy et al., 2005), showing an on average lower proportion of risk taking behaviour (Ruedl et al., 2010) and having less muscle strength than males. In addition, compared to male skiers female skiers do not differ with regard to the date of the last binding adjustment (Ruedl et al., 2010; Ruedl et al., 2011) as well as to deviations from recommended z-values according the ISO 11088 standard (Ruedl et al., 2010). Our results reveal that compared to males, failure of binding release at the moment of accident seems to be a major problem

for females suffering from an injury. Because knee injuries are the most common injuries in alpine skiing and females have a 2-3 fold higher knee injury rate compared to males (Burtscher et al., 2008), any preventive measures reducing these injuries in particular would be of utmost importance from a health perspective as well as from an economical point of view. Importantly, the ISO 11088 standard accepts a deviation of 15 % between the measured release moment ("reference moment") determined according to the setting tables in ISO 8061 and ski binding settings may also lowered or raised by the same magnitude upon request of the skier (Senner, Michel, Lehner & Brügger, 2013). However, this is largely unknown among the overall skier population, but could represent a potential preventive measure, especially for female recreational skiers. One might assume that lowering of the binding settings is increasing the risk of inadvertent release with the consequence of an additional number of falls leading to injuries. However, no increase in injuries from inadvertent binding release through reduced binding settings has been reported (LaPorte, Binet, Fenet & Constans, 2006). Therefore, it seems time to discuss the introduction of a sex factor within the binding settings according to the ISO 11088 standard meaning a lowering of binding settings by 15 % for female skiers.

At least three limitations have to be considered. Firstly, self-reporting to questions might lead to underreporting or overreporting of health-risk behaviours, affected by cognitive and situational factors (Brenner, Billy & Grady, 2003). Secondly, no valid information on injury severity or medical diagnosis was recorded as injured people were interviewed and not the physician treating the patient. Thirdly, injured skier's binding settings have not been measured after the accident. Therefore, we only can speculate that most ski bindings were adjusted correctly according to the ISO 11088 standard because more than 90 % of interviewed people reported a binding adjustment by a professional.

In conclusion, every second female skier in this study reported a failure of binding release at the moment of accident which is considerably higher compared to male skiers although sexes did not differ with regard to the date of the last binding adjustment. Thus, lowering of binding settings in female skiers should urgently be discussed.

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Competing Interests

The authors have declared that no competing interests exist.

Data Availability Statement

All relevant data are within the paper.

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