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Binding function in relation to injury risk in downhill skiing

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ABSTRACT

Time-trend studies suggest that in the recent past, the use of modern equipment and adequately functioning ski bindings have had a preventive effect on injuries. The question of whether a further decrease of injury figures can still be expected from better binding adjustment is investigated in a case-control study ($N = 1,148$) conducted among Dutch skiers. Nonrelease of both bindings directly before injury was associated with a higher risk (odds ratio = 3.3) for lower extremity (LE) injury. Binding release before LE injury was highest (31%) among those for whom adjustment was performed and then confirmed with a test device. The proportion of nonrelease is highest for knee injuries. No effect on injury risk could be found for the time of adjustment, the method of adjustment, or the person performing the adjustment. Direct measurement of binding function seems indispensable. The use of rented or borrowed skis was associated with a higher risk (odds ratio = 1.9) for LE injury. The same holds for ignorance concerning the type of ski and the age of the skis and bindings. We concluded that binding adjustment still seems to be a risk factor open to manipulation. The efficacy of intervention aimed at better adjustment should be studied experimentally.

Downhill skiing has gained enormous popularity over recent decades. As with most other sports, there is a certain risk of injury. Estimates range between 1 and 10 ski injuries per 1,000 skier days.^{2,17,19,29} Differences in reported incidences are partly due to differences in the definitions of a skier and of an injury.²² Furthermore, injury registration methods

often lead to substantial underestimation, especially of those injuries that do not immobilize the skier, e.g., injury of the thumb.¹⁶ The current incidence of serious injury, that is, injury requiring substantial medical treatment, is generally agreed to be in the range of 2 to 4 per 1,000 skier days.^{15,27,34} This figure seems to be much lower than that of a few decades ago.^{15,23,27,30,34}

It is commonly agreed that the development and use of modern ski equipment, especially of release bindings and plastic ski boots, have contributed substantially to the decline in incidence of injury.^{18,23,30} Additional support for this point of view may be seen in the changing pattern of ski injuries over the years. In their review of relevant studies, Hauser and Gläser¹⁶ indicate trends in the proportion of reported ski injuries for different parts of the body as weighted averages over the available studies, noting the occurrence between 1960 and 1980 of a substantial decline (from 80% to 55%) in the proportion of lower extremity injuries, especially of the foot and ankle (45% to 10%). During the same time span, the proportion of tibia fractures declined from 25% to 15%, although knee injuries remained at around 20%. In contrast to the relative decline of lower extremity injuries, there appeared to be an increase in upper extremity injuries, from 10% to 25% between 1960 and 1980, while the proportion of injuries of the head and torso doubled to 20%.

Johnson and his colleagues¹⁸⁻²⁰ introduced the concept of lower extremity equipment related (LEER) injury "... in which the mechanism is consistent with the ski acting as a lever to bend or twist the leg" (Johnson et al.,¹⁹). They classified 80% of the lower extremity (LE) injuries as LEER injuries. Between 1972 and 1978, the LEER injury incidence rate fell by 43%, while the upper body injury rate decreased by only 25%. The incidence of fractured tibiae and sprained ankles especially declined substantially (both by more than 70%).

These time-trend studies suggest that in the recent past, the use of modern equipment and an adequate adjustment

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of the ski binding had a preventive effect on injuries. Ski boots form a functional unit with the bindings. It is recognized that boot properties can dramatically affect release performance.¹² The early models of the modern plastic ski boot (late 1960s and early 1970s) were associated with a sudden increase of isolated fractures of the fibula at the boot top level.^{11,26} Later on, the stiffness characteristics of the boot became more appropriate, but there still seems to be room for improvement of the ski boot design.¹² No data is available on the risks connected to the different types of current ski boots, although one author¹³ warns that binding function may be impaired when the boot sole is made of thermoplastic rubber. This material is still used rather often in boots for children. It seems reasonable to assume that the current ski boots protect the ankle especially. The consequence may be that the twisting forces are transmitted upward to the knee.

Nowadays, the prevalence of modern equipment usage is almost 100%. In order to determine whether a further decrease of injury figures can be expected from a better adjustment of bindings, a case-control study was conducted among Dutch skiers during the 1984/1985 season, with the aim of examining three questions relevant to the topic. First, it was hypothesized that binding release would be less frequent during accidents leading to LEER injury compared to non-LEER injury. Such a difference may be expected and is indeed reported in the literature,^{8,34} although it is doubtful whether an optimally adjusted ski binding will always release in time to prevent a LEER injury. The knee especially seems to be insufficiently protected by the current binding design.^{11,12,20}

The second hypothesis was that adjustment of the bindings would be better among uninjured skiers compared to injured skiers, especially compared to those who had LEER injury. A number of studies seem to confirm this hypothesis to some extent.^{16,18,19,24,34} Bindings of uninjured skiers appear, on average, to be adjusted 50% above the recommended setting.^{9,13} The same holds for skiers who had non-LEER injury. The mean deviation for knee sprains is 85% and for tibia fractures 150%, according to a recent German study.¹⁶ Most observational studies of ski injury have not included the testing of bindings. Instead, information is often collected concerning the time of last adjustment, the method of adjustment, or the person who performed the adjustment. Information is also gathered on the age and ownership of the equipment. In most studies, no clear relation between these proxy measures of binding adjustment and injury risk could be established.^{17,28,32,35} The reason for this may be confounding by other risk factors (e.g., ability) or the imprecision of these proxy measures.

The third hypothesis concerned whether intervention in the form of an adequate adjustment of the binding could prevent LEER injury. A randomized controlled trial was recently performed in Germany¹⁴ for this purpose. Bindings in the experimental group ($N = 460$) were optimally adjusted by the research team. More than 50% of these appeared to be badly adjusted beforehand. Compared to the control

group ($N = 690$), the incidence of LEER injuries was 3.5 times lower in the experimental group.

This article investigates the extent to which the results of our case-control study confirm the hypothesis that Dutch skiers could benefit substantially from better adjustment of their bindings. Cases of injury are divided in an LE and a non-LE injury group. LE injury cases are compared both to controls and non-LE cases with respect to several self-reported characteristics of the skis and bindings. Confounding by several other risk factors is adjusted for by means of stratified analysis and logistic regression. Finally, the evidence from our study is discussed against the background of the relevant literature.

MATERIALS AND METHODS

Both cases of injury and controls from the 1984/1985 season were obtained from the records of a company covering roughly one-third of the market for ski insurance in the Netherlands. Most Dutch skiers are insured. The cases selected were those of skiers who had claimed medical costs as a result of a ski injury that made skiing or other activities impossible for 1 day or longer. All casualties involving a fracture, a dislocation, or a ruptured ligament were selected. Furthermore, a sample of less severe injuries was taken. In addition to this, a number of severely injured skiers that had been transported to the Netherlands by the organization selling the insurance were selected. For every case of injury selected, an equal number of uninjured skiers were chosen by taking the next claim from an uninjured skier (these latter claims were received by the insurance company for other reasons, e.g., loss or theft of ski equipment or luggage).

A questionnaire was sent shortly after the ski holiday to the population thus defined. Reminders were sent after 10 and 20 days. The questionnaire consisted of about 80 questions for the controls and of 120 questions for the cases. For both groups, information was collected in a comparative way on most risk factors mentioned in scientific and popular literature. In addition, injured skiers were questioned about the circumstances of the accident and the subsequent injury. This article primarily deals with the self-reported characteristics of equipment and binding adjustment, although confounding by a number of other risk factors is also taken into account. The separate effect of other categories of risk factors is presented elsewhere.^{3-6,33}

In the data analysis, special attention was given to the adjustment for confounding. Confounded measures of association may arise when the levels of other risk factors (e.g., ability) are unequally distributed over the different levels of the risk factor under study (e.g., binding function). Control for confounding variables is necessary to estimate the independent contribution to the injury risk of the separate risk factors of interest. This was achieved by means of stratification and multivariate analysis (logistic regression). Stratification indicates that weighted averages of the associations of interest are formed over strata homogenous for one or more other risk factors (e.g., age, gender, and ability). Thus,

an estimate of association (odds ratio) that is adjusted for the confounding by some other risk factors is calculated. In multivariate analysis (logistic regression), measures of association are calculated that are simultaneously adjusted for the confounding influence of a large number of other risk factors. This is achieved by means of mathematical modeling. Also, in the resulting logistic model, the phenomenon of statistical interaction is taken into account. This deals with the situation in which the effect of some factors on risk injury is partly dependent on the level of other factors. Odds ratios for the risk associated with a factor of interest can be calculated from the logistic model. Given some assumptions, odds ratios can be interpreted as relative risks. For instance, an odds ratio of 2.0 for beginners compared to more advanced skiers means that beginners have a double risk for injury.

Data analysis was performed with the aid of BMDP (Biomedical Computer Programs P-series)¹ and GLIM (Generalised Linear Interactive Modelling)¹⁰ statistical software. Two steps can be distinguished. First, an elementary analysis was performed, in which confounding by age and gender, and later on ability, were adjusted for. The distribution of risk factors was calculated for cases and controls based on direct standardization for age in three categories (15 to 29, 30 to 44, and 45 to 59 years) and in a number of tables for gender too. Furthermore, odds ratios were calculated as a weighted average over six strata for age and gender using the Mantel-Haenszel method with the corresponding test-based 95% confidence intervals following the method of Miettinen.²¹ In the instances in which confounding by ability was also adjusted for (beginners versus more advanced skiers), eight strata were formed in this procedure.

The second step of data analysis concerned a more complete control for confounding and first order interaction. For this purpose, a logistic model²¹ based on a selection of 25 variables was designed. In the final model, 20 variables remained and 12 interaction terms were included. From the logistic regression coefficients in this model, adjusted odds ratios with their approximate 95% confidence intervals can be calculated.²¹

RESULTS

Response

Response was well over 80% and about the same for injured skiers (84%) and controls (82%). The injured group responded slightly faster. The majority (81%) of the 1,540 respondents practiced downhill skiing only. The others were cross-country skiers or practiced both; this group was excluded from the analysis. A number of skiers (103) did claim medical costs, but appeared not to have been prevented from skiing or other activities for one day or longer. These were also excluded from the analysis. Data on 1,148 downhill skiers were analyzed, consisting of 572 injured skiers and 576 controls.

Between the injured skiers and the controls, slight differences in age and a rather strong difference in gender com-

position was found. Mean age for the injured skiers was 32.0 years and 32.6 years for the controls. These ages are similar to the mean age (32.1 years) of active skiers among a representative sample of the Dutch population.⁷ Forty-six percent of the injured skiers were males, compared to 67% of the controls. Among a representative sample of the Dutch population,⁷ females appeared to go on winter sports holiday as often as males. In our opinion, these figures reflect a selection bias caused by the way the controls were selected. In the Netherlands, males are probably still mentioned more often as the owner of lost or stolen objects, because they are considered to be the head of family. The consequence is that the risks associated with age and gender cannot be estimated from our study. For the same reason, every odds ratio presented is adjusted for confounding by age and gender.

Injuries

A total of 929 injuries were reported by the 572 injured skiers (Table 1). Fifty-four percent of these injuries involved the lower extremities. Knee injuries accounted for 32% of the total injuries, tibia fractures for 6%, and ankle injuries for 7%. Upper extremity injuries were responsible for 20% (thumb, 8%) of injuries, and 26% of the reported injuries involved the head or torso. Table 2 shows a distinction between injured skiers who reported an LE injury and those who did not. Within the groups of LE cases and non-LE cases, a hierarchical subdivision was made. In Table 2, each case is counted only once.

Among the males, 51% were classified as having LE injuries, whereas this figure was as high as 66% for the females. This difference is almost completely the result of the finding that one-third of the female injured skiers reported injuries involving severe damage to the ligaments of the knee. Tibia fractures occurred in 8% of the male skiers and 11% of the female skiers. Among the non-LE cases, severe injury of the shoulder and the thumb were the most frequent.

TABLE 1
Subdivision of all injuries ($N = 929$) reported by injured skiers ($N = 572$), stratified for gender

Grade ^a	Males (418 injured)			Females (511 injured)		
	F	L	R	F	L	R
Lower leg	22	1	16	35	4	18
Knee	5	55	48	13	111	64
Ankle	7	12	8	9	10	16
Other lower extremity	10	1	14	3	2	12
Thumb	7	19	15	6	15	10
Other upper extremity	17	15	23	22	13	24
Shoulder	16	21	19	4	19	14
Other torso	7	5	22	8	3	19
Head or neck	6	0	27 ^b	4	4	49 ^c
Totals	97	129	192	104	181	226

^a F, fracture; L, ligament rupture or dislocation; R, ruptured muscle, contusion, or laceration.

^b Including 11 commotio cerebri.

^c Including 19 commotio cerebri.

TABLE 2
Subdivision of LE injury cases and non-LE cases according to most severe injury mentioned, stratified for gender

	Grade ^a	Males (N = 265) (%)	Females (N = 307) (%)
Lower leg	F	8	11
Knee	L	18	33
Other LE	F	6	5
Other LE	L or R	18	18
Total LE injuries		51	66
Shoulder	F or L	10	6
Thumb	F or L	8	5
Other	F	8	9
Other	L or R	22	14
Total non-LE		49	34
Total		100	100

^a F, fracture; L, ligament rupture or dislocation; R, ruptured muscle, contusion, or laceration.

Release of binding

Thirty percent of the male skiers who had LE injury reported a release of both bindings during the accident that led to injury (Table 3). Among the male skiers who had non-LE injuries, 50% of the accidents involved a release of both bindings. In general, the bindings of female skiers released less often during the situations that led to injury. Only 18% of the LE injured skiers and 34% of the non-LE injured skiers reported release of both bindings. Nonrelease of the bindings during the accident leading to injury was associated with a higher risk for LE injury. The same holds for the release of only one binding. Among the cases of LE injury, the proportion of nonrelease was highest for injuries of the knee (males, 38%; females, 54%). Table 3 gives the odds ratios and the corresponding confidence intervals for males and females separately. The overall odds ratio for nonrelease was 3.3 (confidence interval = 2.1 to 5.3). This means that the risk of sustaining an LE injury (compared to a non-LE injury) was 3.3 times greater for those individuals who had nonrelease than for those who did have binding release. For release of one binding only, the ratio was 2.3 (confidence interval = 1.4 to 3.8).

Characteristics of bindings

In our questionnaire, several questions concerned the adjustment and function of the bindings. To some extent, all of these items are probably associated with the ability of the

skier. It can be imagined, for instance, that more advanced skiers are more likely to own their skis and will have a more adequate knowledge about their equipment than beginners. For this reason, all odds ratios and confidence intervals in this section are, in addition to adjustment for differences in age and gender, based on a stratification for ability as well. Table 4 indicates the prevalence of the variables concerned among LE cases, non-LE cases and controls. Table 5 gives the odds ratios and confidence intervals that can be calculated for these variables.

More than two-thirds of the skiers in the study reported that their bindings had been recently adjusted (Table 4). When it is assumed that the adjustment was performed longer than 1 year ago, among skiers who did not know when their bindings had last been adjusted, it is estimated that roughly 20% of the bindings were adjusted longer than 1 year ago. Table 5 shows that no relation between the time of adjustment and injury risk could be detected.

Proper adjustment of bindings is based on information about the skier (weight, height, tibia size, sex, age, etc.). There are basically two methods for choosing the right setting: the DIN 7881 or "tibia method", and the ISO 8061 or "weight method."⁹ Experts strongly advocate that the function of the binding be confirmed with a test device.²⁵ Almost 50% of the skiers in our study reported using this method of testing for binding adjustment (Table 4). One-third of the skiers mentioned collection of the right information during the procedure, but no test device was used for this group. About 20% of the skiers reported binding adjustment without the relevant information and without using the test device, or were ignorant of the procedure followed. No association between the method of adjustment and injury risk was detected in our study (Table 5).

The majority of bindings were adjusted in a ski shop (Table 4). Adjustment in a ski shop in the ski area (compared to a shop in the Netherlands) was associated with a higher risk for LE injury (Table 5). This holds both for LE injured skiers versus controls and LE injured skiers versus non-LE injured skiers. About 60% of the controls and the non-LE injured skiers owned their own skis (Table 4). The majority of LE injured skiers used rented or borrowed skis. The use of borrowed skis was associated with a higher risk of injury.

No relation between the type of ski and the age of the skis and bindings and injury risk was found.³ Skiers quite often did not know the type (beginner, intermediate, expert) of

TABLE 3
Release of binding among LE injury cases and non-LE injury cases, stratified for gender

	Males (N = 265)				Females (N = 307)			
	LE	non-LE	OR ^a	CI ^b	LE	non-LE	OR ^a	CI ^b
Two bindings	30%	50%	1.0		18%	34%	1.0	
One binding	27%	23%	2.1	(1.0-4.1)	29%	22%	2.7	(1.3-5.7)
No release	33%	13%	3.2	(1.6-6.5)	46%	28%	3.3	(1.7-6.5)
Unknown	10%	13%			7%	17%		
No.	136	129			204	103		

^a Odds ratios (OR) are given as a weighted average over three strata (15-29, 30-44, 45-59 year) (Mantel-Haenszel).

^b 95% confidence intervals (CI) (Miettinen).

TABLE 4
Prevalence of some self-reported characteristics of skis and bindings among LE injury cases, non LE injury cases and controls^a

	LE cases (N = 340) (%)	Non-LE cases (N = 232) (%)	Controls (N = 576) (%)
Time of adjustment			
Recently	71	70	66
1 year ago	10	12	13
>1 year ago	5	5	9
Unknown	14	13	12
Method of adjustment			
With test apparatus	46	47	49
With information only	35	33	32
Without information	16	14	14
Unknown	3	6	5
Place of adjustment			
Ski shop in Holland	46	58	54
Ski shop in ski area	48	30	34
Elsewhere	4	8	8
Unknown	2	4	4
Ownership of skis			
Owned	45	60	62
Rented or borrowed	55	40	38
Knowledge of equipment			
Adequate	59	69	76
Inadequate	41	31	24
Skis at night			
Inside	93	89	95
Outside	7	11	5

^a Adjusted percentages are given based on direct standardization for age (15–29, 30–44, 45–49 years) and gender.

skis or the age of the skis and bindings (in years). This was labelled as “inadequate knowledge” in the analysis. Inadequate knowledge was associated with an elevated risk for injury in general, and even more strongly with the risk for

LE injury. It can be imagined that, besides being associated with age, gender, and ability, knowledge status is also associated with other risk factors for injury. For this reason, knowledge about equipment was included in a logistic model in which mutual confounding and first order interactions among the 20 principal variables in our study was adjusted for. In this logistic model, absence of adequate knowledge appeared to be associated with an odds ratio increasing with the number of times the skier went abroad for a skiing holiday. This first order interaction, however, should be interpreted with some caution, because the number of respondents without adequate knowledge who went frequently on a skiing holiday is small. For them, the confidence interval tends to become very wide (e.g., for 10 holidays, odds ratio = 4.5; confidence interval = 1.9 to 10.1).

The small minority of skiers who usually leave their skis in the open air at night appeared to have a higher injury risk. Within the logistic model, this effect was found only within the subgroup of skiers who did not take ski lessons. Table 5 leads one to infer that the risk for non-LE injury especially increases among those who leave their skis outside at night.

DISCUSSION

The injured skiers included in our study were selected by injury severity. Injured skiers not filing claims and a number of skiers claiming medical costs for relatively minor injuries were not questioned. Furthermore, some severely injured skiers not insured by the company providing the study population were added to the cases group. This selection of more severe injuries serves to increase the contrast between

TABLE 5
Odds ratios and confidence intervals for some self-reported characteristics of skis and bindings, adjusted for ability^a

	Injured skiers vs. controls	LE injured skiers vs. controls	LE injured skiers vs. non-LE injured skiers
Moment of adjustment			
Recently	1.0	1.0	1.0
1 year ago	0.7 (0.4–1.1)	0.7 (0.4–1.2)	0.8 (0.4–1.9)
>1 year ago	0.6 (0.4–1.1)	0.7 (0.3–1.4)	1.1 (0.4–2.5)
Method of adjustment			
With test apparatus	1.0	1.0	1.0
With information only	1.1 (0.8–1.5)	1.1 (0.7–1.7)	1.0 (0.6–1.5)
Without information	1.1 (0.7–1.8)	1.2 (0.7–2.1)	1.2 (0.6–2.5)
Place of adjustment			
Ski shop in Holland	1.0	1.0	1.0
Ski shop in ski area	1.2 (0.9–1.6)	1.6 (1.2–2.2)	2.2 (1.4–3.2)
Elsewhere	0.9 (0.3–3.2)	0.8 (0.3–2.0)	0.8 (0.2–2.7)
Ownership of skis			
Owned	1.0	1.0	1.0
Rented or borrowed	1.3 (1.0–1.8)	1.8 (1.3–2.5)	1.8 (1.2–2.8)
Knowledge about equipment			
Adequate	1.0	1.0	1.0
Inadequate	1.6 (1.2–2.2)	1.9 (1.4–2.8)	1.5 (1.0–2.4)
Skis at night			
Inside	1.0	1.0	1.0
Outside	2.0 (1.2–3.4)	1.5 (0.7–3.1)	0.6 (0.3–1.1)

^a Odds ratios are given as a weighted average over eight strata for age (15–29, 30–59 years), gender and ability (beginners, more advanced) (Mantel-Haenszel) followed by a test-based 95% confidence interval (Miettinen).

injured skiers and controls. There seems to be no reason to postulate that the risk factors contributing to injury risk among this selected group are different from those among the population of Dutch skiers in general.

Despite the fact that our study population is not a random sample of all Dutch downhill skiers, the composition of the group of injured skiers in our study is in reasonable agreement with the summary of the earlier literature provided by Hauser and Gläser,¹⁶ who refer mainly to studies in which for each case, one principal diagnosis was recorded by a physician. In our study, however, the diagnosis was self-reported, and more than one site and type of injury could be mentioned. From this it can be expected that many less severe (secondary) injuries will be mentioned, especially contusions and minor lacerations. In Table 2, only one diagnosis was chosen for each case. The proportion of LE-injured skiers is similar to that of other studies.¹⁶ The same holds for the high proportion of severe knee injuries among females.^{16, 18, 20}

Internal validity can be impaired by selection bias, information bias, and uncontrolled confounding. The central issue in selection bias is whether the group of injured skiers and the group of controls are comparable with respect to relevant factors. We have already mentioned that there is probably some selection bias with respect to age and gender because of the way the controls were selected. This bias, however, is adjusted for in every odds ratio presented. There seems to be no reason to postulate selection bias caused by differential nonresponse. Response was high and in no observable way selective. In theory, the choice of the control group (claim for loss or theft) might also have led to some overrepresentation of new, expensive, and maybe better adjusted equipment among the uninjured skiers in our study. In that case, the postulated (but not observed) risks of inadequate equipment and binding function would have been overestimated by our data. This potential bias does not affect the comparison between LE and non-LE cases.

Information bias is concerned with whether the information gathered is comparable between injured skiers and controls. The choice of the control group makes information bias caused by selective recall less probable. Controls also had a reason to remember the details of their ski holiday. An inherent limitation of our study is that all of the information we gathered was based on self-assessment. Therefore, our study lacked precise and objective information on injury and on the actual function of the bindings. Furthermore, our study is retrospective and, as a consequence of the known outcome (injury or no injury), the assessment of certain risk factors might be influenced. Perceived ability especially might have been underestimated among the injured skiers and/or overestimated among the controls for this reason. Probably, less subjective items, such as the circumstances of binding adjustment, as well as the comparison between LE injured skiers and non-LE injured skiers, are less susceptible to this type of bias.

Uncontrolled confounding is the third and last issue in the assessment of internal validity. The odds ratios in Table

5 are controlled for differences in ability. Furthermore, in the logistic model, every important confounding variable on which we collected information is adjusted for. This, of course, does not exclude bias caused by unmeasured confounding variables, nor confounding caused by imprecise measurement.

For the interpretation of the associations between putative risk factors and injury risk that we did or did not find in our data, credibility is at least as important as statistical significance. Thus, the results of our study must also be interpreted in the context of earlier investigations and biologic plausibility. In this respect, we return to the three questions (hypotheses) stated in the introduction to this article.

The first question was whether binding release was less frequent directly prior to LE injury compared to non-LE injury. Our data seem to confirm this hypothesis. Nonrelease was associated with a more than three-fold risk for LE injury. We also found that the release of only one binding was associated with more than a double accident risk. The fact that among the LE injured skiers, the proportion of nonrelease was the highest for knee injuries supports the hypothesis that the knee is insufficiently protected by the current ski binding design and/or adjustment.^{11, 12, 20} However, some caution is warranted in interpreting these data on binding release. Skiers who have had an LE injury may incorrectly assume that because they were injured, their bindings did not release. Furthermore, inadvertent release may predispose one to a non-LE injury (e.g., of the head or shoulder), thus accounting partly for the increased percentage of release in that group. From our data, it also becomes clear that LE injury can occur in instances in which the binding did release prior to injury. It is doubtful whether an optimally adjusted binding will always release in time to prevent an LE injury. There still seems to be room for further improvement in the design of the ski binding.

The second question dealt with differences in binding adjustment between controls and injured skiers, especially LE injured skiers. In our study, as in those of other investigators,^{17, 28, 32, 35} no clear relation between the moment of adjustment, the method of adjustment, the person performing the adjustment, and injury risk could be demonstrated. Correction for confounding by self-reported ability did not influence this finding, although some uninjured skiers may have overestimated their ability, leading to some residual bias in the estimated odds ratios. It is more probable, however, that our proxy measures of binding adjustment were too insensitive, and possibly too biased as well, to detect the risk of badly adjusted bindings. Direct measurements of binding function among uninjured and injured skiers seems indispensable in observational studies. Some indirect evidence linking prevention with the use of a test device stems from the observation that among these skiers, release of two bindings was reported directly before injury by 31% of the LE injured skiers. For adjustment with information only and adjustment without any information, release of both

bindings was reported to happen in only 26% and 11% of the LE injured skiers, respectively.

The fact that binding adjustment in a ski shop in the ski area was associated with an elevated injury risk compared to adjustment in the Netherlands seems to confirm the widespread but poorly documented opinion that Dutch ski shops perform the binding adjustment more precisely and use a test device more often. Our study seems to confirm the second part of this opinion. Dutch ski shops (67%) used a test device more often than the shops in the ski areas (36%). Furthermore, only 4% of the binding adjustments in Holland were performed without any relevant information. This figure was as high as 28% among the skiers who had their bindings adjusted in a shop abroad. A study directly comparing the quality of binding adjustment in different European countries must be done before reliable conclusions can be drawn from this observation. Rented or borrowed skis were associated with a higher injury risk, also after correction for confounding by ability. This could be an indication of the risks of much used or low quality equipment, or also perhaps, of poorly performed adjustment. Our study is inconclusive on these points. Further research is indicated into these postulated risk factors, which are principally open to manipulation. The association of an absence of knowledge on the type of skis and the age of the skis and bindings with a higher risk may indicate an attitude of negligence. This interpretation is consistent with the finding in the logistic model that the effect of inadequate knowledge increased with increasing winter sport experience: to stay ignorant for many years implies a very indifferent attitude to equipment. Clearly, this interpretation is theoretical and needs to be confirmed in future studies. At first glance, the elevated risk for those who leave their skis outside at night would seem to point to incorrect binding function caused by freezing. This, however, is inconsistent with the fact that the habit of leaving the skis outside especially elevates the risk for non-LE injury. Furthermore, we can think of no plausible explanation for the finding that this variable increases the risk only among those who do not take ski lessons. We tend to consider the effect of leaving the skis outside coincidental within our data.

The third and final question relevant to the topic is whether intervention in the form of adequately adjusting the bindings can prevent LEER injury. We did not investigate this crucial question, which up to this moment has been the subject of only one study.¹⁴ Our findings concerning the release of bindings before injury suggests that there still is much improvement to be made concerning timely release. Whether the solution should be sought in better technical design or in better adjustment of the bindings cannot be determined with certainty from our data. Although two-thirds of the skiers in our study reported recent adjustment and half of our study population said that the proper methods were followed, it may still be worthwhile to test in an experimental design the efficacy of optimal adjustment for Dutch skiers.

CONCLUSION

The risk for LE injury compared to non-LE injury is elevated when no binding release occurs before the injury (odds ratio = 3.3). The proportion of nonrelease is highest for knee injuries, suggesting that there is still much to be done concerning design and adjustment of the bindings.

No effect on the injury risk could be found concerning the moment of adjustment, the method of adjustment, and the person performing the adjustment. It is suggested that direct measurement of binding function is indispensable in observational studies. Skiing on rented or borrowed skis is associated with an elevated injury risk. The same holds for persistent ignorance on the type of skis and the age of the skis and bindings. These observations seem plausible and interpretations are suggested. Further investigations should clarify these risks.

Binding function still seems to be an important risk factor, one that is open to manipulation. Experimental studies in which the bindings of randomly chosen skiers are optimally adjusted could further quantify the current contribution of bad adjustment to injury risk in downhill skiing.

REFERENCES

1. Baker RJ, Nelder JA: *The GLIM System. Release 3*. Oxford, Numerical Algorithms Group, 1978
2. Bouter LM, Knipschild PG: Risicofactoren van skiletseel. *T Soc Gez Zorg* 63: 846-851, 1985
3. Bouter LM, Knipschild PG: *Skirisico's*. Maastricht, Rijksuniversiteit Limburg, 1985
4. Bouter LM, Knipschild PG, Feij JA, et al: Sensation seeking and injury risk in downhill skiing. *Pers Ind Diff* 9: 667-673, 1988
5. Bouter LM, Knipschild PG, Volovics A: Ability and physical condition in relation to injury risk in downhill skiing, in Johnson RJ, Mote CD, (eds): *Skiing Trauma and Safety*. Philadelphia, ASTM, in press, 1989
6. Bouter LM, Knipschild PG, Volovics A: Personal and environmental factors in relation to injury risk in downhill skiing. *Int J Sports Med*, in press, 1989
7. CBS: *Vakantie onderzoek 1984*. 's-Gravenhage, Staatsuitgeverij, 1986
8. Danielsson K, Eriksson E, Jonsson E, et al: Attempts to reduce the incidence of skiing injuries in Sweden, in Johnson RJ, Mote CD, (eds): *Skiing Trauma and Safety*. Philadelphia, ASTM, 1985
9. Delouche G: Bindings' release setting in alpine skiing, in Johnson RJ, Mote CD (eds): *Skiing Trauma and Safety*. Philadelphia, ASTM, 1987
10. Dixon WJ: *BMDP Statistical Software*. Berkeley, University of California Press, 1983
11. Eriksson E, Johnson RJ: The etiology of downhill ski injuries. *Exerc Sport Sci Rev* 8: 1-17, 1980
12. Ettlinger CF, Johnson RJ: The state of the art in preventing equipment-related alpine ski injuries. *Clin Sports Med* 1: 199-207, 1982
13. Gunderson TM: Comparative laboratory tests of release bindings for children and young skiers with special reference to the influence of boot material and boot sole length, in Johnson RJ, Mote CD (eds): *Skiing Trauma and Safety*. Philadelphia, ASTM, 1987
14. Hauser W: Experimental prospective skiing injury study. *Proceedings of the Eighth International Symposium on ski trauma and skiing safety*. Chamonix, ISSS, 1987
15. Hauser W, Gläser H: Verletzungen beim alpinen Skilauf. Veränderungen und Trends. *Deutsche Zeitschr Sportmed* 38: 191-198, 1987
16. Hauser W, Gläser H: *Alpine Skiunfälle und Verletzungen*. München, DSV, 1985
17. Jaffin B: An epidemiologic study of ski injuries: Vail Colorado. *Mt Sinai J Med* 48: 353-359, 1981
18. Johnson RJ, Ettlinger CF: Alpine ski injuries: Changes through the years. *Clin Sports Med* 1: 181-196, 1982
19. Johnson RJ, Ettlinger CF, Campbell RJ, et al: Trends in skiing injuries. *Am J Sports Med* 8: 106-113, 1980
20. Johnson RJ, Pope MH, Weisman G, et al: Knee injury in skiing. *Am J Sports Med* 7: 321-327, 1979
21. Kleinbaum DG, Kupper LL, Morgenstern H: *Epidemiologic Research: Prin-*

- ciples and Quantitative Methods*. Belmont, Lifetime Learning Publications, 1982
22. Knipschild PG, Bouter LM: Risk factors for ski injuries. A crash course on epidemiologic methods with emphasis on comparability in experiments and case-control studies, in Johnson RJ, Mote CD (eds): *Skiing Trauma and Skiing Safety*. Philadelphia, ASTM, in press, 1989
 23. Kuriyama S, Fujimaki E: Current trends in ski injuries and their relationship to recent changes in ski equipment, in Johnson RJ, Mote CD (eds): *Skiing Trauma and Safety*. Philadelphia, ASTM, 1987
 24. Lystad H: A one-year study of alpine ski injuries in Hemsedal, Norway, in Johnson RJ, Mote CD (eds): *Skiing Trauma and Safety*. Philadelphia, ASTM, 1985
 25. Nagel A, Mösch S: Test devices for ski bindings sold in sport shops: State of the art and future development, in Johnson RJ, Mote CD (eds): *Skiing Trauma and Safety*. Philadelphia, ASTM, 1987
 26. Pechlaner S, Philadelphia G: Typical injuries caused by skiing equipment and methods to reduce them. *Int Ser Sports Sci* 5: 131-138, 1978
 27. Shealy JE: Overall analysis of NSAA/ASTM data on skiing injuries for 1978 through 1981, in Johnson RJ, Mote CD (eds): *Skiing Trauma and Safety*. Philadelphia, ASTM, 1985
 28. Shealy JE, Geyer LH, Hayden R: Epidemiology of ski injuries: Effect of method of skill acquisition and release binding accident rates. *Human Factors* 16: 459-473, 1974
 29. Sugawara M, Serita K, Takada Y, et al: Analysis of skiing injuries in Sapporo, Japan, during 1979 through 1984, in Johnson RJ, Mote CD (eds): *Skiing Trauma and Safety*. Philadelphia, ASTM, 1987
 30. Tapper ED: Ski injuries from 1939 to 1976: The Sun Valley experience. *Am J Sports Med* 6: 114-121, 1978
 31. Ungerholm S, Gierup J, Gustavsson J, et al: Skiing safety in children: Adjustment and reliability of bindings. *Int J Sports Med* 5: 325-329, 1984
 32. Ungerholm S, Gustavsson J: Skiing safety in children: A prospective study of downhill injuries and their relation to the skier and his equipment. *Int J Sports Med* 6: 353-358, 1985
 33. Volovics A, Bouter LM, Knipschild PG: Modelling injury risks for downhill skiers, in Bouter LM (ed): *Injury Risk in Downhill Skiing*. Haarlem, De-Vrieseborch, 1988
 34. Young LR, Crane HD: Thumbs up: The changing pattern of ski injuries, in Johnson RJ, Mote CD (eds): *Skiing Trauma and Safety*. Philadelphia, ASTM, 1985
 35. Young LR, Oman CM, Crane H, et al: The etiology of ski injuries: An eight year study of the skier and his equipment. *Orthop Clin North Am* 7: 13-29, 1976