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The effect of helmets on the risk of head and neck injuries among skiers and snowboarders: a meta-analysis

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Abstract

Background: The prevention of head injuries in alpine activities has focused on helmets. However, no systematic review has examined the effect of helmets on head and neck injuries among skiers and snowboarders.

Methods: We searched electronic databases, conference proceedings and reference lists using a combination of the key words "head injury or head trauma," "helmet" and "skiing or snowboarding." We included studies that used a control group; compared skiers or snowboarders with and without helmets; and measured at least one objectively quantified outcome (e.g., head injury, and neck or cervical injury).

Results: We included 10 case–control, 1 case–control/case-crossover and 1 cohort study in our analysis. The pooled odds ratio (OR) indicated that skiers and snowboarders with a helmet were significantly less likely than those without a helmet to have a head injury (OR 0.65, 95% confidence interval [CI] 0.55–0.79). The result was similar for studies that used controls without an injury (OR 0.61, 95% CI 0.36–0.92), those that used controls with an injury other than a head or neck injury (OR 0.63, 95% CI 0.52–0.80) and studies that included children under the age of 13 years (OR 0.41, 95% CI 0.27–0.59). Helmets were not associated with an increased risk of neck injury (OR 0.89, 95% CI 0.72–1.09).

Interpretation: Our findings show that helmets reduce the risk of head injury among skiers and snowboarders with no evidence of an increased risk of neck injury.

Skiing and snowboarding are popular winter activities.[1] Estimates from numerous countries indicate that head injuries account for 9% to 19%, and neck injuries for 1% to 4%, of all injuries reported by ski patrols and emergency departments.[2–11] Rates of head and neck injuries have been reported between 0.09 and 0.46 per 1000 outings.[12] Head and neck injuries are disproportionately represented in cases of severe trauma, and traumatic brain injury is the leading cause of death and serious injury among skiers and snowboarders.[13] As far back as 1983, Oh and Schmid recommended mandatory helmet use for children while skiing.[14]

Many studies of the relation between helmet use and head injuries among skiers and snowboarders have found a protective effect.[15–24] It has been suggested that the use of helmets may increase the risk of neck injury in a crash or fall.[25] This may be more evident among children because they have a greater head:body ratio than adults, and the additional size and weight of the helmet may increase the risk of neck injury in an otherwise routine fall.[26] We conducted a systematic review of the effect of helmets on head and neck injuries among skiers and snowboarders.

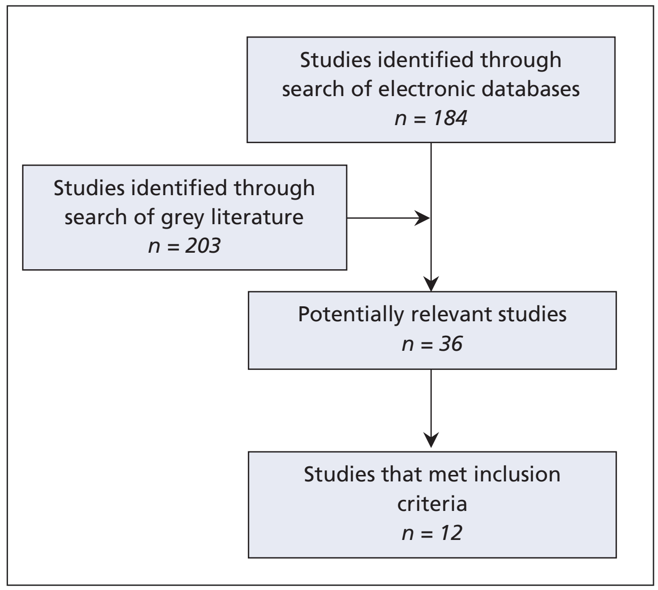

Figure 1: Results of literature search.

Methods

Literature search

We conducted comprehensive literature searches of the following electronic databases: MEDLINE (1950 to November 2008), Academic Search Complete (1948 to November 2008), SPORTDiscus (1982 to November 2008), Embase (1980 to November 2008), ERIC (Education Resources Information Center; 1965 to October 2008), PubMED (1948 to

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November 2008), the Cochrane Central Register of Controlled Trials (CENTRAL; 1991 to November 2008) and SafetyLit (1870 to November 2008). We manually searched the proceedings of the 1st to 16th annual conferences of the International Society of Skiing Safety. We also reviewed the reference lists of included studies. The search strategy is described in Appendix 1 (available at www.cmaj.ca/cgi/content/full/cmaj.091080/DC1). Both published and unpublished studies were considered. We included only English-language studies in the review.[27]

Selection of studies

Two of us (J.C. and K.R.) screened the titles, and abstracts when available, of potentially relevant studies. The same reviewers independently assessed the full text if the study met the following inclusion criteria: (a) cohort, case–control or case-crossover study design; (b) comparison of snowboarders or skiers with and without helmets; and (c) measurement of at least one objectively quantified outcome (e.g., head injury, neck injury, or severity of head or neck injury). Disagreements were resolved by consensus.

Table 1: Description of studies included in a systematic review of the effect of helmets on the risk of head and neck injuries among skiers and snowboarders (part 1 of 2)

Study (country)	Study design	Study population	Sex and age	Snowboarders	Ability	Definition used for head or neck injury	Verification of head or neck injury
Mueller et al.[17] (United States)	Case–control	21 375 injured skiers and snowboarders reported by ski patrol; 4779 with helmet, 16 855 without helmet	Cases (head/neck/face injury): male 69% (2904/3701) Controls (no injury): male 57% (10 057/17 626) Age: NR	Cases: 62% Controls: 59%	Cases: Expert: 1394 Intermediate: 1660 Beginner: 935 Controls: Expert: 4608 Intermediate: 7085 Beginner: 4608	Head injury: injury to scalp or skull above the hairline; includes ear and brain injury Facial injury: injury between lower jaw and hairline Neck injury: NR	NR; ski patrol data
Russell et al.[30] (Canada)	Case–control	47 200 injured skiers and snowboarders reported by ski patrol; helmet use 24.3% among cases, 20.2% among controls	Sex: NR Age: 1–18 yr	55.2%	NR	Neck injury: neck or cervical spine	NR; ski patrol data
Fukuda et al.[24] (Japan)	Case–control	1190 injured snowboarders who sought medical treatment for head injury at nearby medical facility; 92 with helmet, 1098 without helmet	Helmet: male 76% (70/92) Mean age 24.6 (SD 4.04) yr No helmet: male 64% (704/1098) Mean age 22.7 (SD 4.8) yr	100%	Helmet: "Upper" technique level: 31 Other: 61 No helmet: "Upper" technique level: 129 Other: 969	Serious head injury: traumatic amnesia, loss of consciousness, craniofacial fracture or intracranial lesion	Physician data; cases and injured controls recruited from neurosurgery institute
Shealy et al.[23] (United States)	Case–control	4637 injured skiers at a ski resort in Vermont; 1113 with helmet, 3524 without helmet	NR	None	NR	Potentially serious head injury: diagnosed concussion, more severe closed head injury, skull fracture and/or death Less serious head injury: scalp lacerations and abrasions	Physician data; cases diagnosed by hospital personnel or clinic staff
Sulheim et al.[15] (Norway)	Case–control	3562 injured skiers and snowboarders reported by ski patrol; 752 with helmet, 2810 without helmet	Cases (head injury): male 67% (388/576) Age < 13 yr: 78 13–20 yr: 251 > 20 yr: 237 Controls (non-head injury): male 60% (1801/2986) Age < 13 yr: 295 13–20 yr: 766 > 20 yr: 1919	Cases: 44% Controls: 26%	Cases: Expert:108 Good: 186 Intermediate: 147 Beginner: 123 Controls: Expert: 570 Good: 1055 Intermediate: 1005 Beginner: 348	Potentially severe head injury: head injury referred to physician or hospital by ski patrol	NR; ski patrol data
Ekeland et al.[18] (Norway)	Case–control	Skiers and snowboarders with injuries recorded in a central registration of injuries over four major Norwegian ski hills	NR	45%	NR	NR	NR

Assessment of methodologic quality

Two of us (J.C. and K.R.) independently assessed the methodologic quality of the studies using the Downs and Black checklist.[28] This 28-point checklist assesses biases related to reporting, external validity, internal validity and power. Disagreements were resolved by consensus.

Data extraction and analysis

Three of us (J.C., K.R. and V.W.) extracted the following information from the studies: study design, demographic characteristics, data source and results (type and severity of injury and adverse events). The data were checked for completeness and accuracy; disagreements were resolved by consensus.

Agreement on inclusion and methodologic quality of studies was measured with use of the kappa statistic. We used random-effects modelling to generate pooled estimates of effect. When available, adjusted results were extracted over crude results. The effect of helmet use was expressed as odds ratios (ORs) with accompanying 95% confidence intervals (CIs). To explore heterogeneity, we conducted subgroup analyses for

Table 1: Description of studies included in a systematic review of the effect of helmets on the risk of head and neck injuries among skiers and snowboarders (part 2 of 2)

Study	Study design	Study population	Sex and age	Snowboarders	Ability	Definition of head or neck injury	Verification of head or neck injury
Hagel et al.[16] (Canada)	Case–control/ case-crossover	3988 injured skiers and snowboarders reported by ski patrol; 1104 with helmet, 2884 without helmet	Cases (head/neck injury): male 58% (476/824) Age < 15 yr: 322 15–25 yr: 336 > 26 yr: 166 Controls (non-head/ neck injury): male 44% (1457/3294) Age < 15 yr: 1277 15–25 yr: 1185 > 26 yr: 832	47%	Days per season Cases: 1 d: 191 2–10 d: 382 > 11 d: 209 Controls: 1 d: 929 2–10 d: 1690 > 11 d: 591	Potentially severe cases: isolated head or neck injury requiring evacuation by ambulance	NR; ski patrol data
Johnson et al.[20] (Canada)	Case–control	745 snowboarders who reported to hospital emergency department; 410 with helmet, 335 without helmet	Male 67% (501/745) Age ≤ 16 yr	100%	NR	NR	NR
Macnab et al.[21] (Canada)	Case–control	307 injured snowboarders; 131 with helmet, 176 without helmet	Sex NR Age < 13 yr	Helmet: 24% No helmet: 50%	NR	Inconsequential: no treatment or investigation Minor: investigation and local treatment Major: investigation and referral to hospital for further treatment	Physician data; injury examined by physician
Ekeland et al.[19] (Norway)	Case–control	3605 skiers and snowboarders with injuries recorded in a central registration of injuries over four major Norwegian ski slopes; 397 with helmet, 3208 without helmet	NR	34%	Helmet: Beginner: 23% Expert: 16% Cases: Beginner: 13% Expert: 17%	NR	NR; ski patrol data
Machold et al.[2] (Austria)	Cohort	2562 students from 86 schools in Austria during 131 winter sport-weeks; 196 with helmet, 2366 without helmet	NR	NR	100%	NR	Physician data (attending trauma surgeon or local hospital)
Sandegard et al.[22] (Sweden)	Case–control	Injured skiers and snowboarders (*n* = NR) who were part of the Swedish Ski Lift and Ski Areas' Organization injury registration	NR	NR	NR	NR	NR; physician data

Note: NR = not reported, SD = standard deviation.

age, sex, experience, and snowboarding versus skiing. For age, we grouped studies if they used consistent categories. We used the I^2 statistic to measure statistical heterogeneity.[29] We conducted a sensitivity analysis of studies of high (Downs and Black score ≥ 18) and low methodologic quality. We assessed publication bias by examining the estimated measures of effect (i.e., odds ratios) against their standard errors.

Results

Of the 36 potentially relevant studies, we included 12 in our analysis (kappa = 0.87, 95% CI 0.70–1.00) (Figure 1). We excluded the other 24 studies for the following reasons: the study design was inappropriate (15 studies); the study did not examine skiers or snowboarders with and without helmet use (5); and the data were not reported by exposure and outcome (4).

Of the 12 included studies, 10 were case–control studies, 1 was a case–control/case-crossover study, and 1 was a cohort study (Table 1).[2,15–24,30] Five studies were conducted in Europe, one in Asia and six in North America. In the 10 studies from which the data could be obtained, 9829 participants wore helmets and 36 735 did not.[2,15–17,19–21,23,24,30] Criteria for selection of cases included self-reported injuries, reports from ski patrols, insurance registrations and patients reporting to an emergency department. Eleven studies examined head injuries; five of them also examined neck injuries.[15–17,19,21] The twelfth study examined neck injuries only.[30] No study reported deaths. No study described the design, quality or fit of the helmets.

The median score for methodologic quality of the included studies was 20 out of 28 (interquartile range 14.25–21.25) (Table 2). The kappa statistic for the assessment of methodologic quality was 0.65 (95% CI 0.57–0.74).

Helmet use and head injury

In our analysis of the nine studies that compared injured skiers and snowboarders with noninjured controls or controls who had an injury other than a head or neck injury, we found that

Table 2: Methodologic quality of the included studies

Study	Study design	Adequate selection of cases and controls	Adequate assessment of exposure	Adequate assessment of outcome	Adequate control for confounding	Overall score*
Meuller et al.[17]	Case–control	Characteristics given: yes Same population: yes Same period: yes	Described: yes	Described: yes Accurate: yes	Distribution given: yes Adjustment: yes	22
Fukuda et al.[24]	Case–control	Characteristics given: yes Same population: yes Same period: yes	Described: yes	Described: yes Accurate: yes	Distribution given: yes Adjustment: yes	21
Russell et al.[30]	Case–control	Characteristics given: yes Same population: yes Same period: yes	Described: yes	Described: yes Accurate: yes	Distribution given: yes Adjustment: yes	23
Shealy et al.[23]	Case–control	Characteristics given: no Same population: yes Same period: yes	Described: no	Described: yes Accurate: yes	Distribution given: no Adjustment: no	10
Sulheim et al.[15]	Case–control	Characteristics given: yes Same population: yes Same period: yes	Described: yes	Described: yes Accurate: yes	Distribution given: yes Adjustment: yes	21
Ekeland et al.[18]	Case–control	Characteristics given: yes Same population: yes Same period: yes	Described: yes	Described: yes Accurate: yes	Distribution given: yes Adjustment: yes	19
Hagel et al.[16]	Case–control and case-crossover	Characteristics given: yes Same population: yes Same period: yes	Described: yes	Described: yes Accurate: yes	Distribution given: yes Adjustment: yes	22
Johnson et al.[20]	Case–control	Characteristics given: yes Same population: yes Same period: yes	Described: yes	Described: yes Accurate: yes	Distribution given: no Adjustment: no	12
Macnab et al.[21]	Case–control	Characteristics given: yes Same population: yes Same period: yes	Described: yes	Described: yes Accurate: yes	Distribution given: no Adjustment: yes	19
Ekeland et al.[19]	Case–control	Characteristics given: yes Same population: yes Same period: yes	Described: yes	Described: yes Accurate: yes	Distribution given: yes Adjustment: yes	19
Machold et al.[2]	Cohort	Characteristics given: yes Same population: yes Same period: yes	Described: no	Described: yes Accurate: yes	Distribution given: no Adjustment: no	15
Sandegard et al.[22]	Case–control	Characteristics given: no Same population: yes Same period: yes	Described: no	Described: no Accurate: yes	Distribution given: no Adjustment: no	9

*Overall scores for methodologic quality were determined with use of the Downs and Black checklist (maximum score 28).[28]

the use of helmets significantly reduced the risk of head injury.[15–23] The pooled analysis of these studies indicated that the risk was reduced by 35% (OR 0.66, 95% CI 0.55–0.79; I^2 = 75.7%). Machold and associates reported no head injury among those who used helmets.[2] Although their study suggests that helmets are protective, we were unable to obtain an odds ratio and include it in the pooled analysis. However, when we added 0.5 to the cells of the 2 × 2 table to enable calculation of an odds ratio[31] and included this study in the analysis, we found no change in the estimate of effect (OR 0.65, 95% CI 0.55–0.79; I^2 = 72.9%) (Figure 2).

When considering the five studies that compared injured skiers and snowboarders with noninjured controls, we found that the risk of head injury was significantly reduced among those wearing a helmet (OR 0.61, 95% CI 0.44–0.83; I^2 = 75.0%).[15,18,20,21,23] The same was true in the pooled analysis of the five studies that compared injured skiers and snowboarders with controls who had an injury other than a head or neck injury (OR 0.63, 95% CI 0.48–0.83; I^2 = 84.7%).[15–17,19,22]

Four studies examined the effect of helmets on potentially severe head trauma.[15,16,23,24] Sulheim and colleagues reported a significant protective effect (OR 0.43, 95% CI 0.25–0.77),[15] as did Hagel and colleagues (OR 0.44, 95% CI 0.24–0.81).[16] Potentially severe head injuries in these two studies were defined as referral to an emergency physician or hospital for treatment,[15] and head injury requiring evacuation by ambulance.[16] Shealy and colleagues reported no significant difference in the incidence of potentially serious head injury (concussion, severe closed head injury, skull fracture or death) between helmet users and nonusers.[23] Fukuda and colleagues, after adjusting for jumping, reported a nonsignificant effect of helmet use on severe head injuries (traumatic amnesia, loss of consciousness, craniofacial fracture or intracranial lesion) compared with nonserious head injuries (OR 0.66, 95% CI 0.32–1.35).[24]

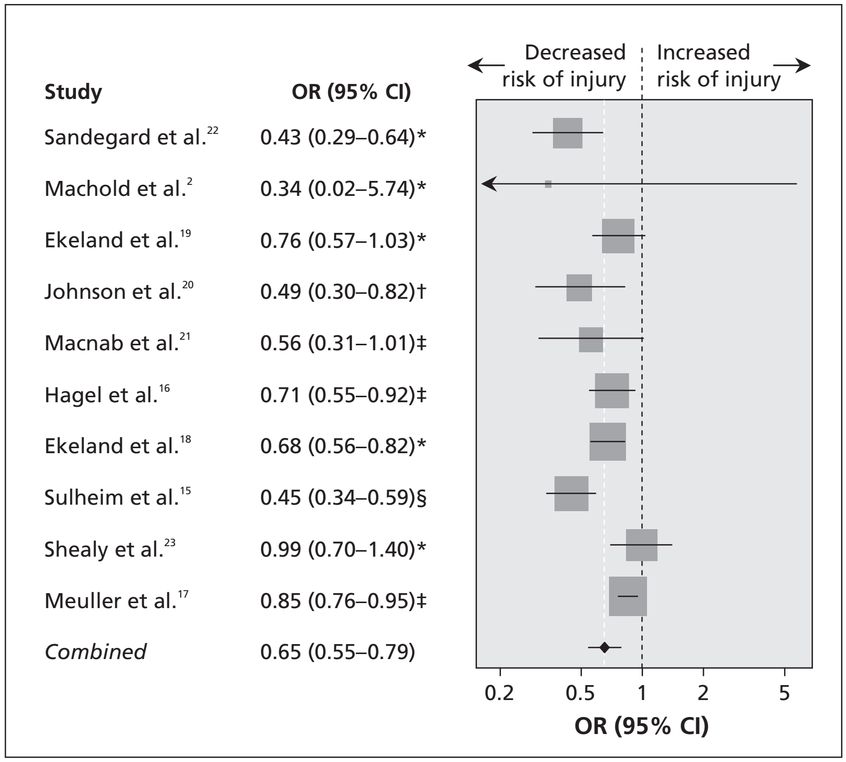

Figure 2: The effectiveness of helmets in preventing head injuries. The size of the data marker corresponds to the relative weight assigned in the pooled analysis. CI = confidence interval, OR = odds ratio. I^2 = 72.9%. *Unadjusted OR and 95% CI calculated from data provided in original study. †OR and 95% CI provided in original study for patients 13–16 years old; an even greater protective effect for helmets was seen among children less than 12 years old (OR 0.21, 95% CI 0.12–0.36). ‡Adjusted OR and 95% CI provided in original study. §OR and 95% CI provided in original study.

Subgroup and sensitivity analyses

The subgroup analyses are presented in Table 3. Among children less than 13 years old, the odds ratio for the effectiveness of helmets in reducing the risk of head injury was 0.39 (95% CI 0.23–0.65; I^2 = 72.2%).[15,17,20,21] The odds ratio among males was 0.80 (95% CI 0.70–0.92), and the odds ratio among females was 0.98 (95% CI 0.80–1.19);[17] however, the *p* value for whether the effect estimates were modified by sex was 0.09. The use of helmets was associated with a significant reduction in the risk of head injury among skiers and snowboarders at the beginner level; however, the *p* value for whether the effect of helmets was modified by experience was 0.15.[17] The association between helmet use and head injury was similar among skiers and snowboarders.

Table 4 describes the sensitivity analyses of methodologic quality. The summary estimates of effect did not vary by the methodologic parameters. None of the differences in methodologic quality accounted for the heterogeneity of the results. Compared with the studies of low methodologic quality (Downs and Black score < 18), the high-quality studies had a slightly more conservative, yet statistically significant, result (OR 0.68, 95% CI 0.55–0.82).

Helmet use and neck injury

The pooled analysis of the six studies that examined the association between the use of helmets and the risk of neck injury showed no increased risk (OR 0.89, 95% CI 0.72–1.09; I^2 = 44.7%) (Figure 3).[15–17,19,21,30] Two of the studies examined the risk of neck injury among children.[21,30] Macnab and colleagues reported an OR of 0.50 (95% CI 0.18–1.25) for the association between cervical spine injury and helmet use among children under 13 years.[21] Preliminary results based on our work suggested no significant association between helmet use and the risk of any neck injury among children after adjustment for age and activity (OR 1.08, 95% CI 0.98–1.20).[30]

Publication bias

Three of the four studies with the largest effect measures (OR < 0.6) all had the largest statistical variability.[2,20,22] Four of the

Table 3: Subgroup analysis of the effect of helmet use on head injuries

Parameter	No. of studies	OR (95% CI)
Age, yr		
< 13	4	0.41 (0.28–0.62)
13–24	1	0.80 (0.69–0.89)
> 25	1	1.13 (0.93–1.36)
< 15	1	0.73 (NR)
15–25	1	0.71 (NR)
> 25	1	0.75 (NR)
Sex		
Male	1	0.80 (0.70–0.92)
Female	1	0.98 (0.80–1.19)
Ability		
Beginner	1	0.69 (0.53–0.89)
Intermediate	1	0.86 (0.72–1.02)
Expert	1	0.92 (0.77–1.09)
Activity		
Skiing	2	0.82 (0.69–0.98)
Snowboarding	2	0.83 (0.75–0.98)
Location		
Park/off-piste (backcountry or out of bounds)	1	0.26 (0.14–0.50)
Prepared runs	1	0.45 (0.31–0.64)
Lift-related*	1	0.52 (0.19–1.38)
Age and activity		
< 13 yr and skiing	1	0.40 (0.20–0.96)
< 13 yr and snowboarding	1	0.18 (0.04–0.74)
13–20 yr and skiing	1	0.52 (0.23–1.19)
13–20 yr and snowboarding	1	0.56 (0.32–0.95)
> 20 yr and skiing	1	0.43 (0.18–1.02)
> 20 yr and snowboarding	1	0.18 (0.03–0.39)

Note: CI = confidence interval, NR = not reported, OR = odds ratio.
*Injured while getting on or off a lift.

six remaining studies had a larger sample size and smaller statistical variability.[16–19] This suggests that smaller studies reporting statistically nonsignificant effect measures may have been less likely to be published.

Interpretation

In our meta-analysis, the use of helmets had a significant protective effect against head injuries among skiers and snowboarders. The pooled analysis showed that the risk of head injury was reduced by 35% with helmet use (95% CI 21%–46%) and that 2–5 of every 10 head injuries among helmet users could be prevented. We found a protective effect among skiers and snowboarders, and among those participating in park/off-piste (backcountry or out-of-bounds) locations and on prepared runs.[15,17,21] Although not statistically significant, there was some suggestion that helmets had a greater protective effect among males than among females, and among skiers and snowboarders of a lower ability level.[17] Our results are similar to those of a recent review of concussions and use of protective equipment in a variety of summer and winter activities.[32]

Two of the studies included in our analysis reported similar, significant protective effects of helmets against potentially severe head injury.[15,16] Conversely, Shealy and colleagues reported no such effect.[23] Differences in the findings may have been due to the definitions used for severe head injury or to the extent of adjustment for confounding variables. In another study by Shealy and colleagues, which we did not include in our review because of a lack of detail about outcomes and the composition of the control group, helmet use was examined among skiers and snowboarders whose primary cause of death was a head injury and those with another primary cause of death (they may have had a nonfatal head injury or a fatal neck injury). The authors found that helmet use was significantly higher among those who died of a non-head-related injury than among those who died of a head injury.[33]

Although wearing a helmet reduces the risk of head injury, there is concern that helmets may increase the risk of neck injury, particularly among children. Our pooled results and the individual studies showed no significant association between helmet use and increased risk of neck injury. This is consistent with biomechanical data showing no increase in neck loads associated with helmet use in simulated snowboarding falls.[34]

The use of helmets may provide a false sense of security, however, and result in more aggressive or dangerous participation, which could increase the risk of injury to other parts of the body.[35] Several studies have examined risk compensation in relation to helmet use among skiers and snowboarders.[15,24,36–39] The evidence is mixed: some of the studies showed increased risk-taking among those who used helmets,[15,39] whereas others showed that helmet users were a more cautious subgroup of participants.[37] Fukuda and associates noted that helmet users were more likely than nonusers to have injuries related to jumping, which indicates that helmet users may attempt more risky manoeuvres.[24] Our work suggests no relation between helmet use and severity of injury or crash circumstances (non-helmet equipment damage, fast self-reported speed, participation in more difficult runs than normal, or jumping-related injury) after adjustment for confounding variables.[36] The available evidence suggests that, if helmet users exhibit compensating behaviour, their level of injury risk is not higher than that of nonusers.

Limitations

Our review has limitations. First, the methodologic quality of the included studies was moderate. The most common shortcoming was an insufficient adjustment for and description of potential confounders. For five of the studies, we had to calculate the odds ratios from the authors' data, and only the crude, unadjusted odds ratio could be calculated.[2,18,19,22,23] However, although adjusted odds ratios were more conservative, the odds ratios for the adjusted and crude pooled estimates were similar and the 95% confidence intervals overlapped.

Two approaches were used to select control groups. Four of the studies included noninjured controls,[18,20,21,23] four included controls with injuries other than head or neck injuries,[16,17,19,22] and one study included both types of controls.[15] The similarity of results in the studies using these approaches provides some support of the validity of both approaches in research of injuries among skiers and snowboarders.

Another limitation was the different definitions of head injury used. Also, the place of diagnosis and the personnel making the diagnosis differed between studies. Definitions of potential confounders, such as age groups and ability, were inconsistently recorded between studies, which made comparisons challenging.

We restricted the review to English-language studies. If English and non-English studies systematically differed in methodologic quality or outcome, then article selection bias would be present. Studies with significant findings are more likely to be in English.[40] If a language bias was present in our review, the effect of helmets may have been overestimated. However, we included studies conducted in regions where skiing and snowboarding are common: Canada, the United States, Europe and Japan.

We made a concerted effort to identify grey literature. Electronic databases, reference lists and conference proceedings were examined in an attempt to discover all literature that would meet our inclusion criteria. If publication bias existed, it would have resulted in an overestimation of the effect of helmets.

We were unable to examine results in terms of the design, quality or fit of the helmets. If helmets were of poor quality or condition, or were worn incorrectly, as has been shown among some users of bicycle helmets,[41] then the effect of helmets would be underestimated relative to their true potential of reducing head injury.[42]

Conclusion

Our pooled analysis of evidence suggests that helmets are effective in reducing the risk of head injury among skiers and snowboarders. We found no significant association between helmet use and an increased risk of neck injury. Based on our findings, we encourage the use of helmets among skiers and snowboarders. Additional, methodologically rigorous research is required to determine which types of helmets provide the best protection.

Table 4: Sensitivity analysis of the effect of helmet use on head injuries

Parameter	No. of studies	OR (95% CI)	Heterogeneity, I^2 value, %
Methodologic quality*			
High (score ≥ 18)	6	0.68 (0.55–0.82)	75.8
Low (score < 18)	4	0.59 (0.35–1.00)	73.1
Study design			
Case–control	9	0.66 (0.55–0.79)	75.7
Cohort	1	0.48 (0.48–0.34)	NA
Adjusted for confounding			
Yes	6	0.68 (0.55–0.82)	75.8
No	4	0.59 (0.35–1.00)	73.1
Adequate outcome assessment			
Yes	9	0.69 (0.58–0.82)	69.3
No	1	0.43 (0.29–0.64)	NA
Adequate exposure assessment			
Yes	7	0.66 (0.54–0.79)	74.0
No	3	0.63 (0.30–1.34)	79.7
Adequate selection of cases and controls			
Yes	8	0.66 (0.54–0.79)	70.0
No	2	0.66 (0.29–1.49)	89.6

Note: CI = confidence interval, NA = not applicable, OR = odds ratio.
*Overall scores for methodologic quality were determined with use of the Downs and Black checklist (maximum score 28).[28]

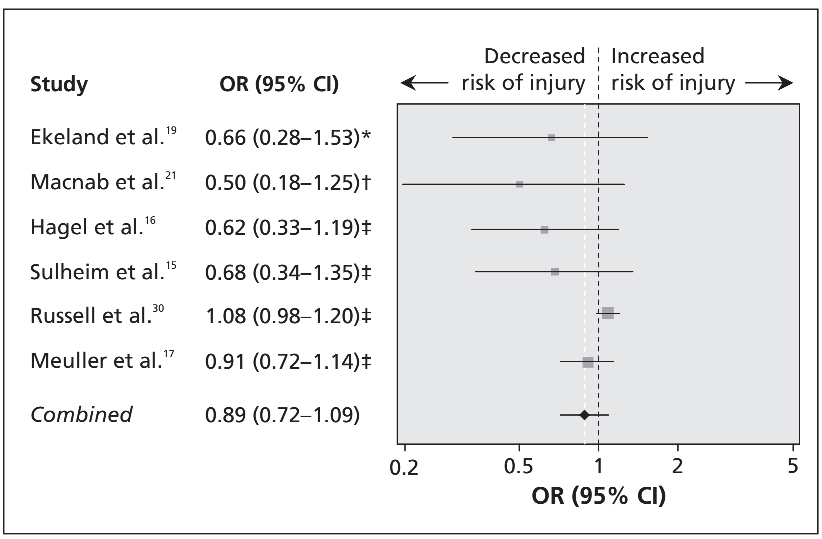

Figure 3: The effect of helmet use on the risk of neck injury. The size of the data marker corresponds to the relative weight assigned in the pooled analysis. CI = confidence interval, OR = odds ratio. I^2 = 44.7%. *Unadjusted OR and 95% CI calculated from data provided in original study. †OR and 95% CI provided in original study. ‡Adjusted OR and 95% CI provided in original study.

This article has been peer reviewed.

Competing interests: None declared.

Contributors: Kelly Russell was involved in the initial conception and design of the study, coordinated the project, assessed studies for inclusion, assessed the methodologic quality of included studies, extracted and checked data, contributed to the data analysis and critically reviewed the manuscript. Josh Christie conducted the literature search, assessed studies for inclusion, assessed the methodologic quality of included studies, extracted and checked data and drafted the manuscript. Brent Hagel was involved in the initial conception and design of the study, contributed to the data analysis and critically reviewed the manuscript. All of the authors approved the final version of the manuscript submitted for publication.

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REFERENCES

1. Bladin C, McCrory P. Snowboarding injuries — an overview. *Sports Med* 1995; 19:358-64.
2. Machold W, Kwasny O, Gassler P, et al. Risk of injury through snowboarding. *J Trauma* 2000;48:1109-14.
3. Hagel BE, Meeuwisse WH, Mohtadi NGH, et al. Skiing and snowboarding injuries in the children and adolescents of Southern Alberta. *Clin J Sport Med* 1999;9:9-17.
4. Made C, Elmqvist LG. A 10-year study of snowboard injuries in Lapland Sweden. *Scand J Med Sci Sports* 2004;14:128-33.
5. Xiang H, Kelleher K, Shields BJ, et al. Skiing- and snowboarding-related injuries treated in US emergency departments, 2002. *J Trauma* 2005;58:112-8.
6. Hagel BE, Pless IB, Platt RW. Trends in emergency department reported head and neck injuries among skiers and snowboarders. *Can J Public Health* 2003;94:458-62.
7. Lamont MK. Ski field injuries: The snowboarders. In: Mote CD Jr, Johnson RJ, Hauser W, et al., editors. *Skiing trauma and safety*. vol. 10. Philadelphia (PA): American Society for Testing Materials; 1996. p. 82-6.
8. Pogorzelski A, McCrory P, Bladin C. Alpine sports injuries in Victoria. *Proceedings of the Australian conference of science and medicine in sport and third national sports injury prevention conference*; 2003 Oct. 25–28; Dickson ACT (Australia): Sports Medicine Australia; 2003. p. 52. Available: http://fulltext.ausport.gov.au/fulltext/2003/acsms/2003ACSMS.pdf (accessed 2010 Jan. 8).
9. Shealy JE, Sundman PD, Johnson RJ, et al. Snowboarding injuries on alpine slopes. *Skiing trauma and safety; seventh international symposium*. Philadelphia (PA): American Society for Testing Materials; 1989. p. 75-81.
10. Davidson TM, Laliotis AT. Snowboarding injuries — a four-year study with comparison with alphine ski injuries. *West J Med* 1996;164:231-7.
11. Bridges EJ, Rouah F, Johnston KM. Snowblading injuries in Eastern Canada. *Br J Sports Med* 2003;37:511-5.
12. Hagel BE, Goulet C, Platt RW, et al. Injuries among skiers and snowboarders in Quebec. *Epidemiology* 2004;15:279-86.
13. Levy AS, Hawkes AP, Hemminger LM, et al. An analysis of head injuries among skiers and snowboarders. *J Trauma* 2002;53:695-704.
14. Oh S, Schmid UD. [Head-injuries in childhood caused by skiing accidents and optimal prevention]. *Z Kinderchir* 1983;38:66-72.
15. Sulheim S, Holme I, Ekeland A, et al. Helmet use and risk of head injuries in alpine skiers and snowboarders. *JAMA* 2006;295:919-24.
16. Hagel BE, Pless IB, Goulet C, et al. Effectiveness of helmets in skiers and snowboarders: Case-control and case crossover study. *BMJ* 2005;330:281
17. Mueller BA, Cummings P, Rivara FP, et al. Injuries of the head, face, and neck in relation to ski helmet use. *Epidemiology* 2008;19:270-6.
18. Ekeland A, Sulheim S, Rodven A, et al. Injury rates and injury types in alpine skiing, telemarking, and snowboarding. In: Johnson R, Shealy JE, Ahlbaumer MG, editors. *Skiing trauma and safety: fifteenth volume*. Philadelphia (PA): American Society for Testing Materials; 2005. p. 31-9.
19. Ekeland A, Rodven A. Injuries in alpine skiing, telemarking, and snowboarding. In: Johnson RJ, Zucco P, Shealy JE, editors. *Skiing trauma and safety: thirteenth volume.* Philadelphia (PA): American Society for Testing Materials; 2001. p. 87-94.
20. Johnson KN, Mohadi NGH, Sasyniuk TM. The prevalence of protective equipment use and injury prevention in snowboarding [abstract]. In: 2001 annual meeting of the Canadian Academy of Sport Medicine. *Clin J Sport Med* 2002;12:65-71.
21. Macnab AJ, Smith T, Gagnon FA, et al. Effect of helmet wear on the incidence of head/face and cervical spine injuries in young skiers and snowboarders. *Inj Prev* 2002;8:324-7.
22. Sandegard J, Eriksson B, Lundkvist S. Nationwide registration of ski injuries in Sweden. In: Mote CD Jr, Johnson RJ, editors. *Skiing trauma and safety.* Philadelphia (PA): American Society for Testing Materials; 1991. p. 170-6.
23. Shealy JE, Johnson RJ, Ettlinger CF. Head trauma and helmet usage in alpine skiing [abstract]. In: 16th International Society of Skiing Safety Conference, Niigata, Japan, 17–23 April 2005. *Knee Surg Sports Traumatol Arthrosc* 2006;14:97.
24. Fukuda O, Hirashima Y, Origasa H, et al. Characteristics of helmet or knit cap use in head injury of snowboarders. *Neurol Med Chir (Tokyo)* 2007;47:491-4.
25. Hunter RE. Skiing injuries. *Am J Sports Med* 1999;27:381-9.
26. Deibert MC, Aronsson DD, Johnson RJ, et al. Skiing injuries in children, adolescents, and adults. *J Bone Joint Surg Am* 1998;80:25-32.
27. Moher D, Pham B, Klassen TP, et al. What contributions do languages other than English make on the results of meta-analyses? *J Clin Epidemiol* 2000;53:964-72.
28. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health* 1998;52:377-84.
29. Higgins JPT, Thompson SG, Deeks JJ, et al. Measuring inconsistencies in meta-analyses. *BMJ* 2003;327:557-60.
30. Russell K, Nettel-Aguirre A, Goulet C, et al. Neck injury risk and helmet use in pediatric skiers and snowboarders [abstract]. Canadian Injury Prevention and Safety Promotion Conference; Toronto; Nov. 11–13, 2007. Available: http://70.25.93.52/natconf/Oral_CIPSPC_Abstracts_2007.pdf (accessed 2010 Jan 25).
31. Breslow NE, Day NE. *The analysis of case–control studies*. Vol. 1 of *Statistical methods in cancer research*. Lyon (France): International Agency for Research on Cancer; 1980. p. 139.
32. Benson BW, Hamilton GM, Meeuwisse WH, et al. Is protective equipment useful in preventing concussion? A systematic review of the literature. *Br J Sports Med* 2009;43(Suppl 1):i56-67.
33. Shealy JE, Johnson RJ, Ettlinger CF. Do Helmets reduce fatalities or merely alter the patterns of death? *J ASTM Int* 2008;5:1-4.
34. Scher I, Richards D, Carhart M. Head contact after catching an edge: an examination of snowboarding helmets [abstract]. In: 16th International Society of Skiing Safety Conference, Niigata, Japan, 17–23 April 2005. *Knee Surg Sports Traumatol Arthrosc* 2006;14:97.
35. Hedlund J. Risky business: Safety regulatons, risk compensation, and individual behaviour. *Inj Prev* 2000;6:82-9.
36. Hagel B, Pless IB, Goulet C, et al. The effect of helmet use on injury severity and crash circumstances in skiers and snowboarders. *Accid Anal Prev* 2005;37:103-8.
37. Scott MD, Buller DB, Andersen PA, et al. Testing the risk compensation hypothesis for safety helmets in alpine skiing and snowboarding. *Inj Prev* 2007;13:173-7.
38. Shealy JE, Ettlinger CF, Johnson RJ, et al. Rates and modalities of death in the U.S.: snowboarding and skiing differences —1991/92 through 1998/99. *Skiing trauma and safety*. Vol. 13. Philadelphia (PA): American Society for Testing Materials; 2000. p. 132-8.
39. Shealy JE, Ettlinger CF, Johnson RJ. How fast do people go on alpine slopes? [abstract] In: Proceedings from the 15th ISSS Conference in Pontresina, Switzerland, 27 April to 2 May 2003. *Knee Surg Sports Traumatol Arthrosc* 2004;12:173.
40. Egger M, Smith GD. Meta-analysis — bias in location and selection of studies. *BMJ* 1998;316:61-6.
41. Lee RS, Hagel BE, Karkhaneh M, et al. A systematic review of correct bicycle helmet use: How varying definitions and study quality influence the results. *Inj Prev* 2009;15:125-31.
42. Rivara FP, Astley SJ, Clarren SK, et al. Fit of bicycle safety helmets and risk of head injuries in children. *Inj Prev* 1999;5:194-7.

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