

# 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.<sup>1</sup> 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.<sup>2–11</sup> Rates of head and neck injuries have been reported between 0.09 and 0.46 per 1000 outings.<sup>12</sup> 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.<sup>13</sup> As far back as 1983, Oh and Schmid recommended mandatory helmet use for children while skiing.<sup>14</sup>

Many studies of the relation between helmet use and head injuries among skiers and snowboarders have found a protective effect.<sup>15–24</sup> It has been suggested that the use of helmets may increase the risk of neck injury in a crash or fall.<sup>25</sup> This

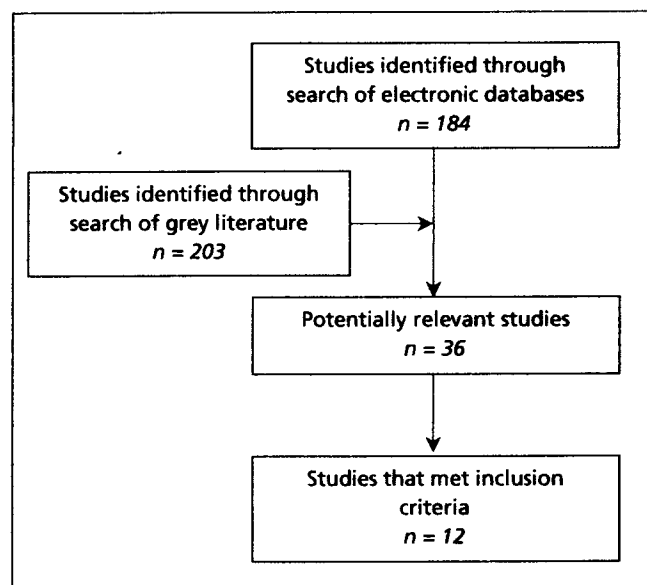


Figure 1: Results of literature search.

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.<sup>26</sup> We conducted a systematic review of the effect of helmets on head and neck injuries among skiers and snowboarders.

## 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](http://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.<sup>27</sup>

### 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. <sup>17</sup> (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. <sup>30</sup> (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. <sup>24</sup> (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. <sup>23</sup> (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. <sup>15</sup> (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. <sup>18</sup> (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.<sup>28</sup> 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 char-

acteristics, 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. <sup>15</sup> (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. <sup>20</sup> (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. <sup>21</sup> (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. <sup>19</sup> (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. <sup>2</sup> (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. <sup>22</sup> (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 *F* statistic to measure statistical heterogeneity.<sup>29</sup> We conducted a sensitivity analysis of studies of high (Downs and Black score  $\geq 18$ ) 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).<sup>2,15–24,30</sup> 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.<sup>2,15–17,19–21,23,24,30</sup> 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.<sup>15–17,19,21</sup> The twelfth study examined neck injuries only.<sup>30</sup> 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. <sup>17</sup>	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. <sup>24</sup>	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. <sup>20</sup>	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. <sup>23</sup>	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. <sup>15</sup>	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. <sup>18</sup>	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. <sup>16</sup>	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. <sup>20</sup>	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. <sup>21</sup>	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. <sup>19</sup>	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. <sup>2</sup>	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. <sup>22</sup>	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).<sup>28</sup>

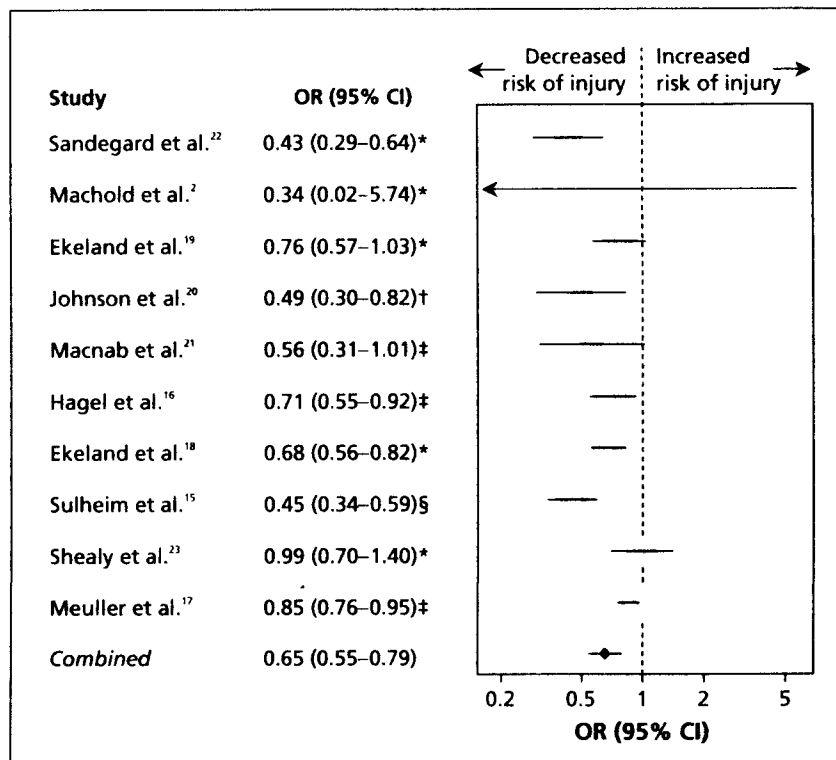
the use of helmets significantly reduced the risk of head injury.<sup>15-23</sup> The pooled analysis of these studies indicated that the risk was reduced by 35% (OR 0.66, 95% CI 0.55-0.79;  $I^2 = 75.7%$ ). Machold and associates reported no head injury among those who used helmets.<sup>2</sup> Although 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  $2 \times 2$  table to enable calculation of an odds ratio<sup>31</sup> 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;  $I^2 = 75.0%$ ).<sup>15,18,20,21,23</sup> 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;  $I^2 = 84.7%$ ).<sup>15-17,19,22</sup>

Four studies examined the effect of helmets on potentially severe head trauma.<sup>15,16,23,34</sup> Sulheim and colleagues reported a significant protective effect (OR 0.43, 95% CI 0.25-0.77),<sup>15</sup> as did Hagel and colleagues (OR 0.44, 95% CI 0.24-0.81).<sup>16</sup> Potentially severe head injuries in these two studies were defined as referral to an emergency physician or hospital for treatment,<sup>15</sup> and head injury requiring evacuation by ambulance.<sup>16</sup> 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.<sup>23</sup> 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 non-serious head injuries (OR 0.66, 95% CI 0.32-1.35).<sup>24</sup>

### 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;  $I^2 = 72.2%$ ).<sup>15,17,20,21</sup> 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);<sup>17</sup> 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.<sup>17</sup> The association between helmet use and head injury was similar among skiers and snowboarders.



**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.

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).<sup>15-17,19,21,30</sup> Two of the studies examined the risk of neck injury among children.<sup>21,30</sup> 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.<sup>21</sup> 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).<sup>30</sup>

### Publication bias

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

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

Parameter	No. of studies	OR (95% CI)
<b>Age, yr</b>		
< 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)
<b>Sex</b>		
Male	1	0.80 (0.70–0.92)
Female	1	0.98 (0.80–1.19)
<b>Ability</b>		
Beginner	1	0.69 (0.53–0.89)
Intermediate	1	0.86 (0.72–1.02)
Expert	1	0.92 (0.77–1.09)
<b>Activity</b>		
Skiing	2	0.82 (0.69–0.98)
Snowboarding	2	0.83 (0.75–0.98)
<b>Location</b>		
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)
<b>Age and activity</b>		
< 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.<sup>16–19</sup> 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.<sup>15,17,21</sup> Although not statisti-

cally 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.<sup>17</sup> 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.<sup>32</sup>

Two of the studies included in our analysis reported similar, significant protective effects of helmets against potentially severe head injury.<sup>15,16</sup> Conversely, Shealy and colleagues reported no such effect.<sup>23</sup> 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.<sup>33</sup>

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.<sup>34</sup>

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.<sup>35</sup> Several studies have examined risk compensation in relation to helmet use among skiers and snowboarders.<sup>15,24,36–39</sup> The evidence is mixed: some of the studies showed increased risk-taking among those who used helmets,<sup>15,39</sup> whereas others showed that helmet users were a more cautious subgroup of participants.<sup>37</sup> 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.<sup>24</sup> 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.<sup>36</sup> 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.<sup>2,18,19,22,23</sup> 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,<sup>18,20,21,23</sup> four included controls with injuries other than head or neck injuries,<sup>16,17,19,22</sup> and one study included both types of controls.<sup>15</sup> 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.<sup>40</sup> 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,<sup>41</sup> then the effect of helmets would be underestimated relative to their true potential of reducing head injury.<sup>42</sup>

## Conclusion

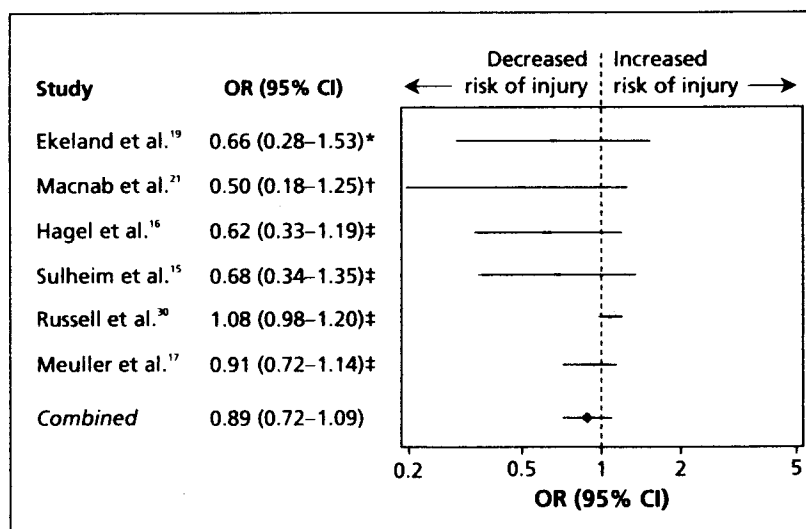
Our pooled analysis of evidence suggests that helmets are effective in reducing the risk of head injury among skiers and snowboarders. We found no significant association between helmet use and an increased risk of neck injury. Based on our findings, we encourage the use of helmets among skiers and snowboarders. 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>I</i> <sup>2</sup> value, %
<b>Methodologic quality*</b>			
High (score ≥ 18)	6	0.68 (0.55–0.82)	75.8
Low (score < 18)	4	0.59 (0.35–1.00)	73.1
<b>Study design</b>			
Case-control	9	0.66 (0.55–0.79)	75.7
Cohort	1	0.48 (0.48–0.34)	NA
<b>Adjusted for confounding</b>			
Yes	6	0.68 (0.55–0.82)	75.8
No	4	0.59 (0.35–1.00)	73.1
<b>Adequate outcome assessment</b>			
Yes	9	0.69 (0.58–0.82)	69.3
No	1	0.43 (0.29–0.64)	NA
<b>Adequate exposure assessment</b>			
Yes	7	0.66 (0.54–0.79)	74.0
No	3	0.63 (0.30–1.34)	79.7
<b>Adequate selection of cases and controls</b>			
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).<sup>43</sup>



**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. *P* = 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.

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**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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