

Review

# Incidence of injuries in professional snow sports: A systematic review and meta-analysis

Xue-Lei Fu<sup>a</sup>, Lin Du<sup>a</sup>, Yi-Ping Song<sup>a</sup>, Hong-Lin Chen<sup>b,\*</sup>, Wang-Qin Shen<sup>a,\*</sup>

<sup>a</sup> School of Medicine, Nantong University, Nantong 226001, China

<sup>b</sup> School of Public Health, Nantong University, Nantong 226019, China

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## Abstract

**Purpose:** The study aimed to conduct a comprehensive systematic review and meta-analysis of injury incidence in professional skiers and snowboarders.

**Methods:** We systematically searched PubMed, Web of Science, and MEDLINE for studies on injury incidence published from inception to April 2020. Injury data were extracted, alongside information on injury location, severity, type, cause, and sport discipline. Incidence of injuries was presented per 1000 athlete-days, with 95% confidence intervals (95% CIs).

**Results:** The search identified 462 articles, and 22 were included in our review. The overall incidence of injuries among professional skiers and snowboarders was 3.49 per 1000 athlete-days (95%CI: 2.97–4.01). Lower extremity had the highest injury incidence (1.54 per 1000 athlete-days, 95%CI: 1.24–1.84). Incidence rates of slight, mild, moderate, and severe injuries were 0.26, 0.31, 0.57, and 0.59 per 1000 athlete-days, respectively. Contusion had the highest incidence rate (1.82 per 1000 athlete-days, 95%CI: 1.01–2.63). The most common cause of injury was contact trauma (3.20 per 1000 athlete-days, 95%CI: 1.32–5.08). Freestyle skiing had the highest incidence rate (6.83 per 1000 athlete-days, 95%CI: 4.00–9.66), and Nordic skiing had the lowest rate (2.70 per 1000 athlete-days, 95%CI: 1.94–3.46).

**Conclusion:** Professional skiers and snowboarders have a substantial risk of sustaining injuries. Our findings can be used to inform the planning and provision of healthcare for elite participants in different snow sports.

**Keywords:** Incidence; Injury; Skiing; Snowboarding

## 1. Introduction

The Winter Olympic Games will be hosted by China in 2022 and are expected to mobilize millions of people to embrace winter sports. Recreational alpine skiing is one of the most popular winter sports, attracting several hundred million people worldwide.<sup>1,2</sup> In the United States, approximately 17 million people participate in snow-skiing and snowboarding every year.<sup>3</sup> These 2 snow sports often share the same slopes and facilities.<sup>4</sup> Generally, skiing-related injuries are the outcome of a complex multiple interaction of internal risk factors, including age, sex, and skill level, as well as external risk factors, including the environment and the ski-boot-binding equipment.<sup>5–7</sup>

An analysis from Australia reported that skiing and snowboarding have the highest incidence of injury among snow sports.<sup>8</sup> It is estimated that emergency departments in the United States treat 200,000 injuries related to skiing and snowboarding annually, and a majority of patients are adults.<sup>9,10</sup> Although most patients are discharged on the same day, roughly 7000 require hospitalization each year.<sup>9</sup> Skiers are often admitted to the floor or the operating room, while snowboarders are frequently sent to the intensive care unit.<sup>11</sup> Experienced skiers and snowboarders are more likely to sustain an injury resulting from jumps, while accidental falls are the most common cause of injury among beginners.<sup>12,13</sup>

The majority of the available data suggests that experienced athletes tend to gain additional health benefits,<sup>14–17</sup> but athletes are still exposed to great risks of injury. Risk of injury is perceived as an inherent part of elite sports, because

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\* Corresponding authors.

E-mail addresses: [honglinyjs@126.com](mailto:honglinyjs@126.com) (H.-L. Chen), [Christina105@126.com](mailto:Christina105@126.com) (W.-Q. Shen).

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athletes always try to push the limits of performance.<sup>18</sup> Bianco et al.<sup>19</sup> reported that elite skiers are likely to gamble with their health to avoid missing an important competition or losing a spot on the team.

Little is known about injury incidence in professional snow sports. The availability of large datasets that combine clinical information with health outcomes would optimize prevention for individuals and populations,<sup>20</sup> and identifying the incidence of injuries would provide information for applying preventive measures. Therefore, a systematic meta-analysis was performed to estimate the incidence of injuries in professional snow sports. The secondary aim was to determine the injury incidence as it relates to location, severity, type, cause, sport discipline, the sex of participants, and events leading to an injury.

## 2. Methods

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.<sup>21</sup>

### 2.1. Search strategy

Three electronic databases (PubMed, Web of Science, and MEDLINE) were systematically searched from inception to April 2020. The searches combined terms related to “skiing”, “alpine skiing”, “cross-country skiing”, “freestyle skiing”, “Nordic skiing”, “ski jumping”, “snowboarding”, “injury”, “professional”, and “elite”. The terms were adjusted according to individual database specifications (Supplementary Table 1). We limited the search to studies that were available in English. The reference lists of retrieved articles were hand searched for additional studies.

### 2.2. Study selection

Studies eligible for inclusion had to fulfill the following criteria: (1) studies that included participants who were professional skiers or snowboarders engaged in professional national or international competitions or who had studied at elite national sports schools after passing a strict entrance examination, (2) studies that reported injury incidence (the number of new injuries occurring in the population during a specific duration of time) among professional athletes or that provided sufficient data for calculation, (3) studies that were original research articles, and (4) studies that went through an independent peer-review process. Studies that did not meet the following criteria were excluded from our meta-analysis: (1) case reports, intervention studies, qualitative studies, editorial commentaries, systematic reviews, or abstracts and (2) studies that did not report measures of athlete-days or follow-up duration.

Two reviewers (XLF and LD) initially screened the titles, abstracts, and reference lists of studies based on the selection criteria. The full-text versions of articles were retrieved when titles and abstracts met the selection criteria. Any discrepancies regarding the selection process were discussed by the 2 reviewers, and a third external reviewer (HLC) was consulted if consensus could not be reached.

### 2.3. Data extraction

The following information was independently extracted by 2 reviewers (XLF and LD): (1) general study characteristics (authors, publication year, and study design), (2) description of the surveyed population (sport discipline, female/male, age, and body mass index (BMI)), (3) epidemiological data (injury, athlete-days, distribution of injuries by location, severity, type, cause, sex, and events leading to an injury). For studies that did not provide the number of athlete-days, it was approximated from follow-up duration and sample size.

### 2.4. Risk of bias assessment

Quality assessment was conducted according to the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.<sup>22</sup> This tool assesses items including study population, exposure, and outcome measures, whether the exposure was assessed prior to outcome measurement, whether the timeframe was sufficient and the number of participants lost to follow-up after baseline. Two reviewers (XLF and YPS) independently assessed included studies and recorded the number of checklist items fulfilled. Discrepancies in assessment were resolved by discussion. Study quality of each study was assessed and reported as poor (score of 0–5), fair (score of 6–9), or good (score of 10–14).

### 2.5. Statistical analysis

Injury incidence in each study was calculated (i.e., the number of injuries divided by 1000 athlete-days). Where the number of injuries equaled zero, 0.5 was substituted to allow for stable calculations in meta-analysis. The  $I^2$  statistic was used to quantify heterogeneity and describe the proportion of total variation resulting from heterogeneity.<sup>23</sup> A random effect model was applied where statistically significant heterogeneity ( $I^2 > 50\%$ ) was detected; otherwise, a fixed effect model was used.

Pooled estimates of injury incidence were summarized in forest plots for the following groups: (1) overall injury incidence, (2) location of injuries (upper extremity vs. lower extremity vs. head/neck vs. trunk), (3) severity of injuries (slight (1–3 days) vs. mild (4–7 days) vs. moderate (8–28 days) vs. severe (>28 days)), (4) type of injuries (fracture vs. sprain vs. strain vs. meniscus and cartilage vs. contusion vs. impingement vs. laceration, abrasion, and skin lesion vs. muscle cramps and spasm vs. other), (5) cause of injuries (overuse vs. contact vs. non-contact vs. other), (6) sport discipline of injuries (alpine skiing vs. freestyle skiing vs. Nordic skiing vs. snowboarding), (7) sex-specific injuries, and (8) training vs. competition injuries.

Publication bias was detected using funnel plot and Egger’s test. The possible influence of the following variables on the model was analyzed through meta-regression: median registration period, mean age, and mean BMI. In addition, time trends were represented by median registration period. For statistical tests, a significance level of  $p < 0.05$  was applied throughout. Injury data extracted from the included studies were analyzed using STATA Version 12.0 (Statacorp., College Station, TX, USA).

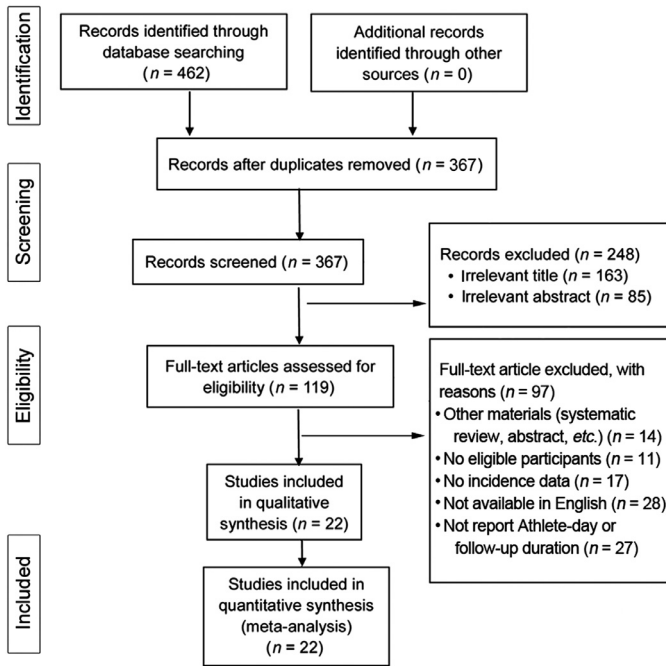


Fig. 1. Flow diagram for identifying studies.

### 3. Results

#### 3.1. Descriptive characteristics of the studies

As shown in the flow diagram (Fig. 1), the electronic search yielded 367 nonduplicate articles. The full texts of 119 studies

were retrieved and assessed for eligibility, of which 97 were subsequently excluded. Thus, 22 studies between 2005 and 2020 were included in the study. Participants included a total of 12,335 professional skiers or snowboarders.<sup>24–45</sup> The mean age ranged from 11.7 years to 23.0 years, and the mean BMI ranged from 17.9 kg/m<sup>2</sup> to 22.2 kg/m<sup>2</sup> overall. A total of 16<sup>24–35,38,39,42,45</sup> of the included studies had a prospective study design, and 6<sup>36,37,40,41,43,44</sup> studies used a retrospective study design. The detailed data are presented in (Supplementary Table 2). A total of 14 studies<sup>24,26–28,32–36,38,39,42,43,45</sup> were considered to be of good quality, 7 studies<sup>25,29,31,37,40,41,44</sup> were of fair quality, and 1 study<sup>30</sup> was of poor quality (Supplementary Table 3).

#### 3.2. Overall injury incidence

Of the included 22 studies, the injury incidence of snow sports varied greatly. The overall incidence was 3.49 injuries per 1000 athlete-days (95% confidence interval (CI): 2.97–4.01) from random effect models. The level of heterogeneity in the analysis was high ( $I^2 = 97.3\%$ ;  $p = 0.000$ ). Fig. 2 displays a summary of the overall injury incidence. Significant publication bias was found by Egger's test ( $p = 0.000$ ) and visual inspection of the funnel plot asymmetry. Neither the registration period ( $p = 0.079$ ), the age ( $p = 0.500$ ) nor BMI ( $p = 0.392$ ) had an impact on injury incidence.

#### 3.3. Location of injury

A total of 17 studies reported location of injuries.<sup>24,27–29,31–34,36–41,43–45</sup> Lower extremity injuries had

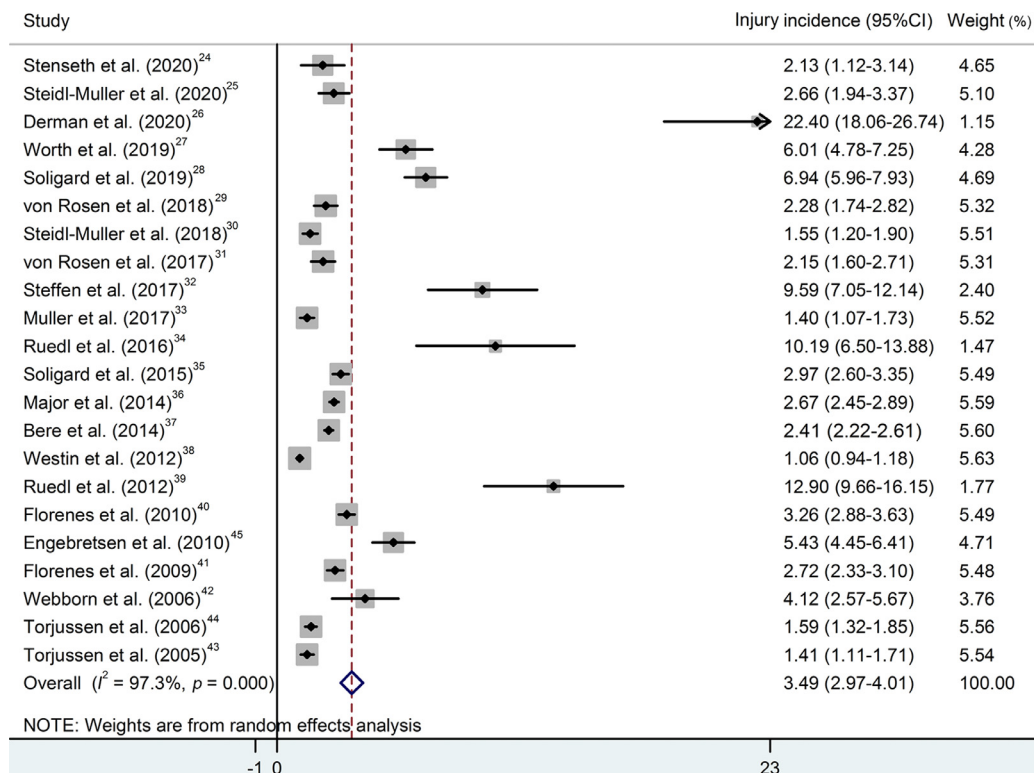


Fig. 2. Forest plot for the overall injury incidence in professional snow sports. 95%CI = 95% confidence interval.

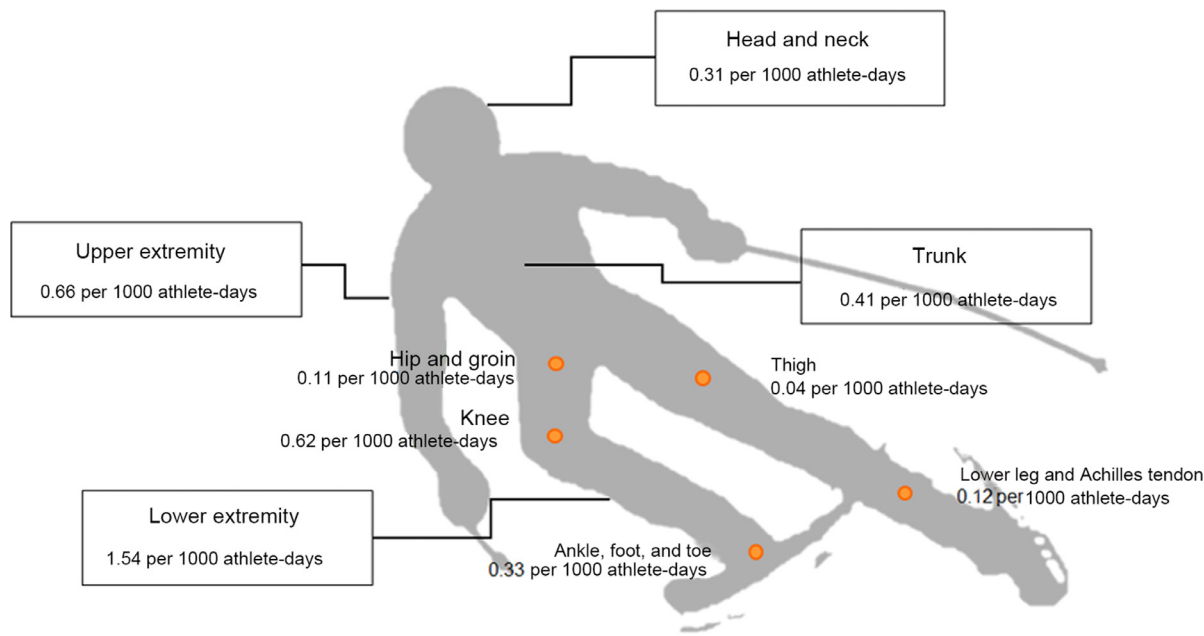


Fig. 3. Injury incidence rates by location of injuries.

the highest injury incidence (1.54 per 1000 athlete-days, 95%CI: 1.24–1.84;  $I^2 = 95.4\%$ ), followed by upper extremity (0.66 per 1000 athlete-days, 95%CI: 0.51–0.82;  $I^2 = 92.3\%$ ), trunk (0.41 per 1000 athlete-days, 95%CI: 0.30–0.51;  $I^2 = 90.4\%$ ), and head and neck injuries (0.31 per 1000 athlete-days, 95%CI: 0.21–0.41;  $I^2 = 90.2\%$ ). Additionally, 15 studies reported data of lower extremity injuries.<sup>24,27–29,31,32,34,36,38–41,43–45</sup> The incidence was represented in descending order: knee (0.62, 95%CI: 0.47–0.78;  $I^2 = 88.5\%$ ), ankle, foot, and toe (0.33, 95%CI: 0.22–0.44;  $I^2 = 90.5\%$ ), lower leg and Achilles tendon (0.12, 95%CI: 0.07–0.17;  $I^2 = 81.0\%$ ), hip and groin (0.11; 95%CI: 0.06–0.16;  $I^2 = 78.9\%$ ), and thigh (0.04, 95%CI: 0.02–0.07;  $I^2 = 43.6\%$ ) (Fig. 3).

### 3.4. Severity of injury

A total of 7 studies provided information on severity of injuries.<sup>24,30,33,37,38,40,41</sup> Incidence rates of slight, mild, moderate, and severe injuries were 0.26 (95%CI: 0.19–0.33;  $I^2 = 45.7\%$ ), 0.31 (95%CI: 0.14–0.48;  $I^2 = 95.8\%$ ), 0.57 (95%CI: 0.51–0.64;  $I^2 = 20.6\%$ ), and 0.59 (95%CI: 0.35–0.82;  $I^2 = 94.4\%$ ) per 1000 athlete-days, respectively. (Fig. 4).

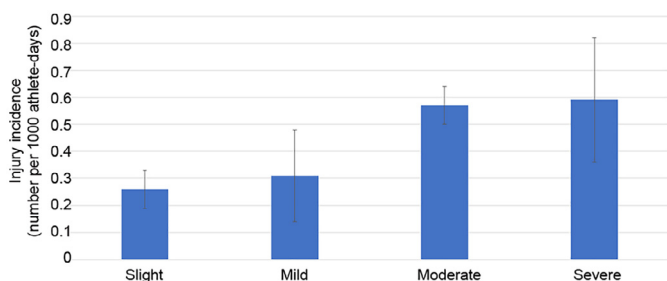


Fig. 4. Injury incidence rates by severity of injuries.

### 3.5. Type of injury

A total of 6 studies were included in the pooled analysis.<sup>24,28,32,34,39,45</sup> The most common type of injury was contusion 1.82 (95%CI: 1.01–2.63;  $I^2 = 84.7\%$ ), followed by sprain 1.48 (95%CI: 1.07–1.89;  $I^2 = 41.3\%$ ); other 1.17 (95%CI: 0.60–1.74;  $I^2 = 80.3\%$ ); strain 0.66 (95%CI: 0.33–1.00;  $I^2 = 59.2\%$ ); fracture 0.57 (95%CI: 0.38–0.76;  $I^2 = 7.8\%$ ); laceration, abrasion, and skin lesion 0.26 (95%CI: 0.01–0.52;  $I^2 = 72.3\%$ ); meniscus and cartilage 0.16 (95%CI: 0.04–0.28;  $I^2 = 14.1\%$ ); and impingement 0.07 (95%CI: 0.00–0.14;  $I^2 = 0.0\%$ ) per 1000 athlete-days. No statistical significance was found for muscle cramps and spasm (Supplementary Fig. 1).

### 3.6. Cause of injury

The cause of injuries was reported in 5 studies.<sup>28,32,34,39,45</sup> Contact trauma was the most common cause of injury (3.20 per 1000 athlete-days, 95%CI: 1.32–5.08;  $I^2 = 94.2\%$ ) compared with the other causes. Incidence rates of non-contact trauma, overuse injuries, and other injuries were 2.38 per 1000 athlete-days (95%CI: 1.52–3.24;  $I^2 = 75.0\%$ ), 1.16 per 1000 athlete-days (95%CI: 0.59–1.73;  $I^2 = 74.0\%$ ), and 0.97 per 1000 athlete-days (95%CI: 0.48–1.46;  $I^2 = 68.9\%$ ), respectively (Supplementary Fig. 2).

### 3.7. Sport discipline of injury

A total of 21 studies provided an indication of sport discipline of injuries.<sup>24,26–45</sup> Freestyle skiing had the highest incidence rate (6.83 per 1000 athlete-days, 95%CI: 4.00–9.66;  $I^2 = 92.6\%$ ), followed by snowboarding (3.99 per 1000 athlete-days, 95%CI: 2.86–5.12;  $I^2 = 95.6\%$ ), alpine skiing (3.57 per 1000 athlete-days, 95%CI: 2.77–4.36;  $I^2 = 96.7\%$ ), and Nordic skiing (2.70 per



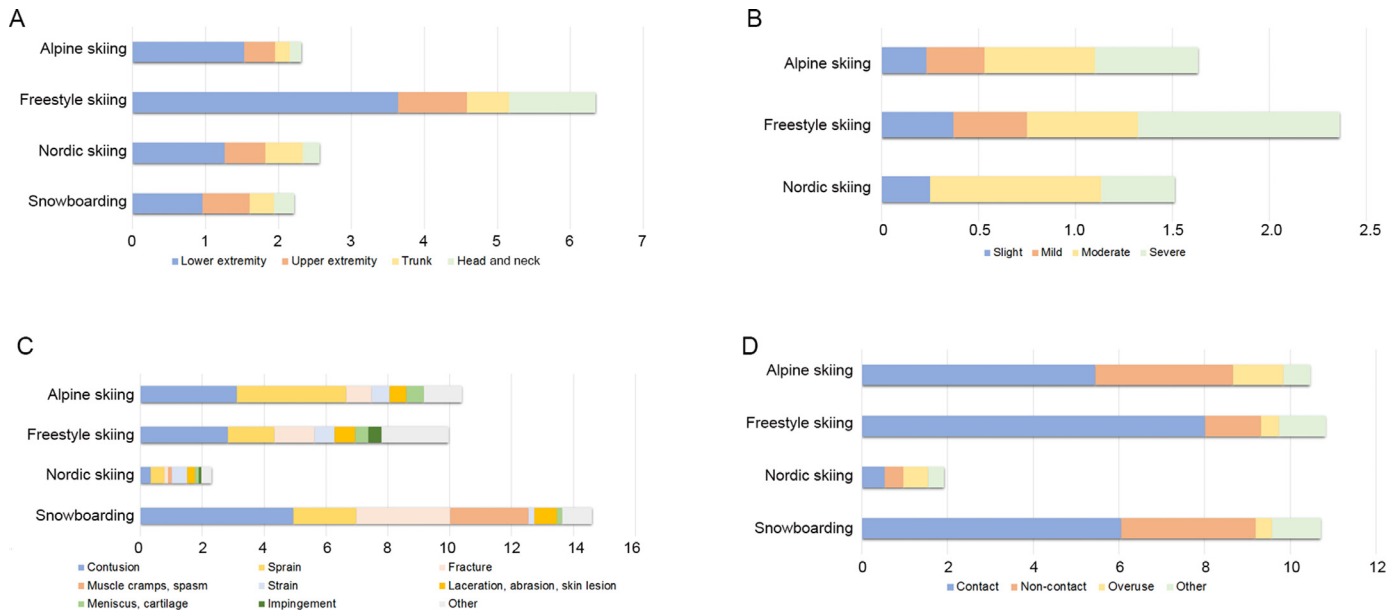


Fig. 5. Incidence proportion of (A) injury location, (B) severity, (C) type, and (D) cause in different snow sports.

1000 athlete-days, 95%CI: 1.94–3.46;  $I^2 = 87.2\%$ ) (Supplementary Fig. 3). Fig. 5 and Supplementary Table 4 show the incidence proportion of injury location, severity, type, and cause.

3.8. Sex-specific injury

A total of 10 studies reported injury data.<sup>28,31,32,34,37,39–42,45</sup> The pooled incidence among males was 2.46 injuries per 1000 athlete-days (95%CI: 1.84–3.07;  $I^2 = 94.3\%$ ) (Supplementary Fig. 4), and among females was 2.10 injuries per 1000 athlete-days (95%CI: 1.62–2.58;  $I^2 = 91.8\%$ ) (Supplementary Fig. 5). Fig. 6 displays the time trend among males and females.

3.9. Training versus competition injury

A total of 15 studies in our analysis allowed us to compare training injuries and competition injuries.<sup>24,28,31,32,34–38,40–45</sup> The incidence in training injuries (1.74 per 1000 athlete-days, 95%CI: 1.30–2.18;  $I^2 = 98.2\%$ ) was higher than in competition

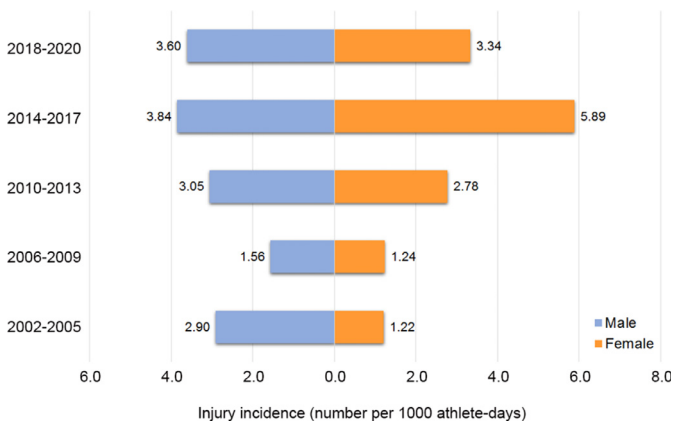


Fig. 6. Injury incidence of time trends among males and females.

injuries (1.16 per 1000 athlete-days, 95%CI: 0.93–1.39;  $I^2 = 91.8\%$ ) (Supplementary Fig. 6).

4. Discussion

We conducted an in-depth meta-analytic systematic review that assesses the injury incidence of professional snow sports. The pooled incidence of injuries across studies was 3.49 per 1000 athlete-days. Incidence rates for alpine skiing, freestyle skiing, Nordic skiing, and snowboarding were 3.57, 6.83, 2.70, and 3.99 per 1000 athlete-days, respectively. A large body of research suggests that snowboard cross and halfpipe, aerial and halfpipe skiing and ski cross, and downhill alpine skiing events are present the greatest risk of injuries.<sup>28</sup>

Among all World Cup alpine skiing injuries, approximately 45% occur during competitions and only 25.1% during various forms of training on snow.<sup>46</sup> It is reported that almost all injuries occur while the alpine ski racer is turning or landing.<sup>47</sup> The most frequently injured body parts are the knee and the lower leg, with sprains of the anterior cruciate ligament being the most common type.<sup>46,48</sup> Interestingly, in our analysis we found that sprain injury and lower extremity injury were both common among alpine skiers, but detailed diagnoses of these injuries are too few to calculate injury incidence targeting a specific diagnosis. Additionally, knee pain and low back pain are reported to be the most frequent overuse injuries in alpine skiing.<sup>49</sup>

The results of our study found that the injury incidence of the head or neck in freestyle skiing was highest compared with the other snow sports. This finding is reasonable since all freestyle disciplines include aerial elements.<sup>50</sup> Moreover, our analysis has also shown that contact trauma is the main cause of freestyle skiing injuries. Randjelovic et al.<sup>51</sup> analyzed video of elite freestyle ski cross and pointed out that the main cause of

injury was unintentional skier-opponent contact when jumping, bank turning and rolling. This observation confirms our findings to some extent.

Nordic skiing had the lowest injury incidence among all snow sports, with a rate of 2.70 per 1000 athlete-days. Previous studies have reported that the incidence rate among athletes competing in national squads versus professional clubs was 0.02 per 1000 athlete-days and 0.09 per 1000 athlete-days, respectively.<sup>52</sup> Our study aimed to determine global injury incidence, while the study by Ketterl<sup>52</sup> was conducted based on a specific region with a small sample size. Regional differences might help to explain why our study found a higher rate of injuries.

When elite snowboarders perform difficult maneuvers at high speed, the lower extremities often sustain amplified levels of force, and these athletes tend to suffer from injuries that are of greater severity.<sup>53</sup> As expected, lower extremity injuries were found to have the highest snowboarding-related injury incidence rate in our study. In the United States, incidence rates of lower extremity injuries presenting to emergency departments were reported to be 19 injuries per 1,000,000 person-years for snowboarders.<sup>54</sup> Emergency departments reported that there was an overall decrease in snowboarding-related injuries from 2010 to 2016 in the United States. Among snowboarding injuries, the most prevalent injury type was fractures, with fractures of the upper extremities being most likely.<sup>55</sup> However, in our study fractures were the second most common injury type. Since our study was based on professional athletes rather than the general population, this difference might be expected.

In our study, snow sports injuries were more common among males. Male athletes are deemed to be “superhuman”, and their mental health is frequently overlooked.<sup>56</sup> Although athletes are more likely to experience depression compared with the general population,<sup>57</sup> conformity to traditional masculine gender norms and the stigma of mental illness often deters male athletes from seeking help.<sup>58,59</sup> This situation creates a vicious circle for the male athlete and influences his personal and sporting life, resulting in performance issues and in turn increasing the risk of injury.<sup>56</sup>

To improve performance, athletes must modify their training load, particularly increases in frequency, duration, and intensity. However, training and competition stress often lead to temporary decrements in physical performance and significant levels of fatigue, increasing the risk of injury.<sup>60</sup> When athletes are unable to cope with their stress, other emotions, such as chronic anger, hostility, confusion, depression, apathy, or anxiety, can occur. Additionally, more and more pressure to achieve elite sport performance has led to earlier specialization in snow sports and may contribute to an increased rate of overuse injury and sport burnout.<sup>61</sup>

An injury has a great impact on a professional athlete since it may portend the end of the athlete’s playing career.<sup>62</sup> Therefore, injury prevention plays an important role in elite sports.<sup>19</sup> It is particularly important for sports medicine physicians to have the information required to counsel athletes regarding safer snow sport participation and to recognize and treat their

most common injuries. Additionally, clinicians and coaches should formulate appropriate exercise prescriptions to strengthen, maintain, or restore health and physical fitness for snow sport athletes.<sup>63</sup> These athletes should be informed about physical and mental health issues that may contribute or detract from excellence in performance and career longevity.

Our study has some weaknesses. First, there was substantial statistical heterogeneity across the included studies ( $I^2 = 97.3\%$ ), which may be explained by the broad time frame that was covered across the included studies. Elite skiers or snowboarders from as early as 2001 through to 2018 were included as participants in the studies. Precise data on athlete-days were not made available in many of the studies, so the true injury incidence was likely underestimated. Second, there was a risk of bias identified in several studies. A total of 6 (27.3%) of the 22 included studies collected data retrospectively, which may have led to a risk of bias. Despite our systematic and comprehensive search, there was undeniably a risk for publication and language bias.

## 5. Conclusion

Our meta-analysis provides evidence that injury incidence in snow sports is very high, with a rate of 3.49 injuries per 1000 athlete-days. The lower extremities were the most frequently injured, and contusion was the most common type of injury. Contact trauma was the main cause of injuries. However, injury characteristics in different snow sports varied significantly. Our findings can inform the planning and provision of healthcare to elite skiers, snowboarders, and other snow sport participants. Clinicians and coaches should be aware of the common diagnoses and develop appropriate injury prevention strategies targeted specific snow sports. Future studies should focus on developing training programs for skiers and snowboarders in order to reduce the risks of long-term injury.

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## Authors’ contributions

XLF developed the search strategy, drafted the published protocol, led data extraction and critical appraisal, and drafted the final manuscript; LD contributed to the abstract screening, data extraction, critical appraisal of the data and critical review of the manuscript; YPS contributed to the design of the study, interpretation of the data analysis and statistical calculations and critical review of the manuscript; HLC and WQS contributed to the design of the study, acted as the guarantor of the study, developed the search strategy, performed, supervised and refereed data extraction, reviewed the data analysis, contributed to drafting the manuscript and critically reviewed the final manuscript. All authors have read and approved the final

version of the manuscript, and agree with the order of presentation of the authors.

### Competing interests

The authors declare that they have no competing interests.

### Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jshs.2020.10.006.

### References

- Cusimano MD, Kwok J. The effectiveness of helmet wear in skiers and snowboarders: A systematic review. *Br J Sports Med* 2010;44:781–6.
- Russell K, Christie J, Hagel BE. The effect of helmets on the risk of head and neck injuries among skiers and snowboarders: A meta-analysis. *CMAJ* 2010;182:333–40.
- Associate NSA. *National skier and snowboarder visits, 2011–1979*. Available at: <http://www.nsa.org/media/68045/NSAA-facts-about-skiing-snowboarding-safety-10-1-12.pdf%02012>. [accessed 15.02.2020].
- Smartt PF, Chalmers DJ. Searching hospital discharge records for snow sport injury: No easy run? *Int J Inj Contr Saf Promot* 2012;19:93–100.
- Burtscher M, Gatterer H, Flatz M, et al. Effects of modern ski equipment on the overall injury rate and the pattern of injury location in Alpine skiing. *Clin J Sport Med* 2008;18:355–7.
- Sulheim S, Holme I, Rødven A, Ekeland A, Bahr R. Risk factors for injuries in alpine skiing, telemark skiing and snowboarding—case-control study. *Br J Sports Med* 2011;45:1303–9.
- Bahr R, Krosshaug T. Understanding injury mechanisms: A key component of preventing injuries in sport. *Br J Sports Med* 2005;39:324–9.
- Siesmaa EJ, Clapperton AJ, Twomey D. Hospital-treated snow sport injury in Victoria, Australia: A summary of 2003–2012. *Wilderness Environ Med* 2018;29:194–202.
- Xiang H, Kelleher K, Shields BJ, Brown KJ, Smith GA. Skiing- and snowboarding-related injuries treated in U.S. emergency departments, 2002. *J Trauma* 2005;58:112–8.
- Nathanson BH, Ribeiro K, Henneman PL. An analysis of US Emergency Department visits from falls from skiing, snowboarding, skateboarding, roller-skating, and using nonmotorized scooters. *Clin Pediatr (Phila)* 2016;55:738–44.
- Wasden CC, McIntosh SE, Keith DS, McCowan C. An analysis of skiing and snowboarding injuries on Utah slopes. *J Trauma* 2009;67:1022–6.
- Hume PA, Lorimer AV, Griffiths PC, Carlson I, Lamont M. Recreational snow-sports injury risk factors and countermeasures: A meta-analysis review and Haddon Matrix Evaluation. *Sports Med* 2015;45:1175–90.
- Ruedl G, Kopp M, Burtscher M, Bauer R, Benedetto K. Causes and factors associated with collisions on ski slopes. *Sportverletz Sportschaden* 2013;27:100–4. [in German].
- Zwiers R, Zantvoord FW, Engelaer FM, van Bodegom D, van der Ouderaa FJ, Westendorp RG. Mortality in former Olympic athletes: Retrospective cohort analysis. *BMJ* 2012;345:e7456. doi:10.1136/bmj.e7456.
- Clarke PM, Walter SJ, Hayen A, Mallon WJ, Heijmans J, Studdert DM. Survival of the fittest: Retrospective cohort study of the longevity of Olympic medallists in the modern era. *Br J Sports Med* 2015;49:898–902.
- Teramoto M, Bungum TJ. Mortality and longevity of elite athletes. *J Sci Med Sport* 2010;13:410–6.
- Kujala UM, Sarna S, Kaprio J, Koskenvuo M. Hospital care in later life among former world-class Finnish athletes. *JAMA* 1996;276:216–20.
- Bolling C, Delfino Barboza S, van Mechelen W, Pasmán HR. Letting the cat out of the bag: Athletes, coaches and physiotherapists share their perspectives on injury prevention in elite sports. *Br J Sports Med* 2020;54:871–7.
- Bianco T, Malo S, Orlick T. Sport injury and illness: Elite skiers describe their experiences. *Res Q Exerc Sport* 1999;70:157–69.
- Fu MR, Kurnat-Thoma E, Starkweather A, et al. Precision health: A nursing perspective. *Int J Nurs Sci* 2020;7:5–12.
- Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Ann Intern Med* 2009;151:264–9.
- National Institutes of Health. *Quality assessment tool for observational cohort and cross-sectional studies*. Available at: <https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools>. [accessed 18.02.2020].
- Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med* 2002;21:1539–58.
- Stenseth OMR, Barli SF, Martin RK, Engebretsen L. Injuries in elite women's ski jumping: Surveillance through the 2017–18 FIS World Cup season. *Br J Sports Med* 2020;54:44–8.
- Steidl-Müller L, Hildebrandt C, Müller E, Raschner C. Relationship of changes in physical fitness and anthropometric characteristics over one season, biological maturity status and injury risk in elite youth ski racers: A prospective study. *Int J Environ Res Public Health* 2020;17:364. doi:10.3390/ijerph17010364.
- Derman W, Runciman P, Jordaan E, et al. High incidence of injuries at the Pyeongchang 2018 Paralympic Winter Games: A prospective cohort study of 6804 athlete days. *Br J Sports Med* 2020;54:38–43.
- Worth SGA, Reid DA, Howard AB, Henry SM. Injury incidence in competitive cross-country skiers: A prospective cohort study. *Int J Sports Phys Ther* 2019;14:237–52.
- Soligard T, Palmer D, Steffen K, et al. Sports injury and illness incidence in the PyeongChang 2018 Olympic Winter Games: A prospective study of 2914 athletes from 92 countries. *Br J Sports Med* 2019;53:1085–92.
- von Rosen P, Heijne A, Frohm A, Fridén C, Kottorp A. High injury burden in elite adolescent athletes: A 52-week prospective study. *J Athl Train* 2018;53:262–70.
- Steidl-Müller L, Hildebrandt C, Müller E, Fink C, Raschner C. Limb symmetry index in competitive alpine ski racers: Reference values and injury risk identification according to age-related performance levels. *J Sport Health Sci* 2018;7:405–15.
- von Rosen P, Floström F, Frohm A, Heijne A. Injury patterns in adolescent elite endurance athletes participating in running, orienteering, and cross-country skiing. *Int J Sports Phys Ther* 2017;12:822–32.
- Steffen K, Moseid CH, Engebretsen L, et al. Sports injuries and illnesses in the Lillehammer 2016 Youth Olympic Winter Games. *Br J Sports Med* 2017;51:29–35.
- Müller L, Hildebrandt C, Müller E, Oberhoffer R, Raschner C. Injuries and illnesses in a cohort of elite youth alpine ski racers and the influence of biological maturity and relative age: A two-season prospective study. *Open Access J Sports Med* 2017;8:113–22.
- Ruedl G, Schnitzer M, Kirschner W, et al. Sports injuries and illnesses during the 2015 Winter European Youth Olympic Festival. *Br J Sports Med* 2016;50:631–6.
- Soligard T, Steffen K, Palmer-Green D, et al. Sports injuries and illnesses in the Sochi 2014 Olympic Winter Games. *Br J Sports Med* 2015;49:441–7.
- Major DH, Steenstrup SE, Bere T, Bahr R, Nordsletten L. Injury rate and injury pattern among elite World Cup snowboarders: A 6-year cohort study. *Br J Sports Med* 2014;48:18–22.
- Bere T, Flørenes TW, Nordsletten L, Bahr R. Sex differences in the risk of injury in World Cup alpine skiers: A 6-year cohort study. *Br J Sports Med* 2014;48:36–40.
- Westin M, Alricsson M, Werner S. Injury profile of competitive alpine skiers: A five-year cohort study. *Knee Surg Sports Traumatol Arthrosc* 2012;20:1175–81.
- Ruedl G, Schobersberger W, Pocecco E, Blank C, Engebretsen L, Soligard T, et al. Sport injuries and illnesses during the first Winter Youth Olympic Games 2012 in Innsbruck, Austria. *Br J Sports Med* 2012;46:1030–7.
- Flørenes TW, Heir S, Nordsletten L, Bahr R. Injuries among World Cup freestyle skiers. *Br J Sports Med* 2010;44:803–8.
- Flørenes TW, Bere T, Nordsletten L, Heir S, Bahr R. Injuries among male and female World Cup alpine skiers. *Br J Sports Med* 2009;43:973–8.
- Webborn N, Willick S, Reeser JC. Injuries among disabled athletes during the 2002 Winter Paralympic Games. *Med Sci Sports Exerc* 2006;38:811–5.

43. Torjussen J, Bahr R. Injuries among competitive snowboarders at the national elite level. *Am J Sports Med* 2005;**33**:370–7.
44. Torjussen J, Bahr R. Injuries among elite snowboarders (FIS Snowboard World Cup). *Br J Sports Med* 2006;**40**:230–4.
45. Engebretsen L, Steffen K, Alonso JM, et al. Sports injuries and illnesses during the Winter Olympic Games 2010. *Br J Sports Med* 2010;**44**:772–80.
46. Spörri J, Kröll J, Gilgien M, Müller E. How to prevent injuries in alpine ski racing: What do we know and where do we go from here? *Sports Med* 2017;**47**:599–614.
47. Bere T, Flørenes TW, Krosshaug T, et al. A systematic video analysis of 69 injury cases in World Cup alpine skiing. *Scand J Med Sci Sports* 2014;**24**:667–77.
48. Kim S, Endres NK, Johnson RJ, Ettliger CF, Shealy JE. Snowboarding injuries: Trends over time and comparisons with alpine skiing injuries. *Am J Sports Med* 2012;**40**:770–6.
49. Steidl-Müller L, Hildebrandt C, Raschner C, Müller E. Challenges of talent development in alpine ski racing: A narrative review. *J Sports Sci* 2019;**37**:601–12.
50. Steenstrup SE, Bere T, Bahr R. Head injuries among FIS World Cup alpine and freestyle skiers and snowboarders: A 7-year cohort study. *Br J Sports Med* 2014;**48**:41–5.
51. Randjelovic S, Heir S, Nordsletten L, Bere T, Bahr R. Injury situations in Freestyle Ski Cross (SX): A video analysis of 33 cases. *Br J Sports Med* 2014;**48**:29–35.
52. Ketterl R. Recreational or professional participants in Nordic skiing. Differences in injury patterns and severity of injuries. *Unfallchirurg* 2014;**117**:33–40. [in German].
53. Wijdicks CA, Rosenbach BS, Flanagan TR, et al. Injuries in elite and recreational snowboarders. *Br J Sports Med* 2014;**48**:11–7.
54. DeFroda SF, Gil JA, Owens BD. Epidemiology of lower extremity injuries presenting to the emergency room in the United States: snow skiing vs. snowboarding. *Injury* 2016;**47**:2283–7.
55. Seleznev A, Shah NV, Desai R, et al. Trends of snowboarding-related fractures that presented to emergency departments in the United States, 2010 to 2016. *Ann Transl Med* 2018;**6**:200. doi:10.21037/atm.2018.04.32.
56. Souter G, Lewis R, Serrant L. Men, mental health and elite sport: A narrative review. *Sports Med Open* 2018;**4**:57. doi:10.1186/s40798-018-0175-7.
57. Mummery K. Essay: Depression in sport. *Lancet (London, England)* 2005;**366**Suppl. 1:S36–7.
58. Seidler ZE, Dawes AJ, Rice SM, Oliffe JL, Dhillon HM. The role of masculinity in men's help-seeking for depression: A systematic review. *Clin Psychol Rev* 2016;**49**:106–18.
59. Tristian RD, Yusuf A, Fitriyasaki R, Wahyuni SD, Nihayati HE. Perceived barriers on mental health services by the family of patients with mental illness. *Int J Nurs Sci* 2017;**5**:63–7.
60. Jones CM, Griffiths PC, Mellalieu SD. Training load and fatigue marker associations with injury and illness: A systematic review of longitudinal studies. *Sports Med* 2017;**47**:943–74.
61. Sabato TM, Walch TJ, Caine DJ. The elite young athlete: Strategies to ensure physical and emotional health. *Open Access J Sports Med* 2016;**7**:99–113.
62. Leach RE, Paul GR. Injury and disability in the professional athlete. *Clin Orthop Relat Res.* 1987;**221**:68–76.
63. Bu B, Hou LR, Zhou XL, et al. Research progress on exercise prescription: A systematic review. *J Evid Based Med* 2010;**10**:1359–66.