# Characteristics of Sports Injuries in Athletes During the Winter Olympics

## A Systematic Review and Meta-analysis

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**Background:** Athletes in the Winter Olympic Games are subject to high injury rates given the physical demands of sports. Comprehensive data regarding injury characteristics in these athletes are limited.

**Purpose:** To summarize and analyze data regarding the incidence and characteristics of sports injuries occurring in the Winter Olympic Games.

**Study Design:** Scoping review; Level of evidence, 4.

**Methods:** A systematic review of the PubMed, EMBASE, Web of Science, and China National Knowledge Infrastructure databases was conducted. Included were studies reporting the incidence of sports injuries during the Winter Olympics Games from 1995 through 2021. From 168 studies initially retrieved, 4 studies (8824 athletes, 1057 injured athletes) were included. A single-group meta-analysis of sports injury characteristics was performed, with subgroup analysis performed according to the different sports, injury locations, and injury types. Injury severity (time lost from sport) and mechanism were also assessed.

**Result:** The overall injury incidence rate (IIR) during the Winter Olympic Games was 9.6% (95% CI, 4.1%-19.8%). Snow sports were associated with the highest IIR (11.3%), with the top 3 events being the snowboard cross event in snowboarding (31.4%), the aerials event in freestyle skiing (28.6%), and the slopestyle event in snowboarding (27.7%). The most common injury locations were the knee (IIR = 20.0%; 95% CI 17.9%-22.0%), head (IIR = 10.6%; 95% CI, 9.4%-11.9%), and ankle (IIR = 8.2%; 95% CI 7.8%-8.7%). The most common injury types were contusion/hematoma/bruise (IIR = 29.9%; 95% CI 29.7%-30.0%), sprain (dislocation, subluxation, instability, ligamentous, rupture) (IIR = 21.9%; 95% CI 21.4%-22.3%), and strain (muscle rupture, tear, tendon rupture) (IIR = 11.3%; 95% CI 11.0%-11.6%). Regarding injury severity, most athletes had no time lost from sport (64.5%); 24.0% lost fewer than 7 days, and 11.5% lost more than 7 days. The most common injury mechanism was noncontact-related injury (63.3%).

**Conclusion:** In Winter Olympics sports, snow-sport injuries were more common than those associated with other sports, and the most common injury location was the knee. Most injuries did not require time loss, and the most were noncontact-related injuries.

**Keywords:** injury prevention; sports injury; systematic review; Winter Olympic Games

The modern Olympics Games are considered the pinnacle of all sporting events.[29] With the rise in the number of participants, an increasing risk of musculoskeletal disorders, sports injuries, and chronic diseases may be observed in elite athletes during their careers.[10,37] Because the winter Olympics sports are characterized by greater speed, higher height, and more intense competition than those associated with the summer Olympics sports, the rate of sports injuries in the Winter Olympic Games is higher than that in the Summer Olympic Games.[24,32] Moreover, once injured, it is difficult for elite athletes to return to their preinjury levels, and many are forced to retire.[14,34] Consequently, it is important for the International Olympic Committee (IOC) to protect athlete health and prevent sport injuries. With the increasing recognition of the characteristics of sports injuries in the Winter Olympic Games,

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a more reliable understanding of the injury patterns during the Olympic Games has been gained, leading to the better prevention of sport injuries in these elite athletes.[18,25]

We therefore believe it important to describe the trends in injury incidence, body location, injury type and severity, and mechanism to build a foundation for injury prevention and protection of athlete health. The purpose of this research was to summarize and analyze the incidence and characteristics of sports injuries occurring in the Winter Olympic Games. We hypothesized that the injury rate of snow sports would be higher and that the most common injury location would be in the lower extremity, with these injury types being contusions/hematomas/bruising with minimal time lost from sport.

## METHODS

### Search Strategy

The current systematic review was registered in the International Prospective Register of Systematic Reviews (PROSPERO), and the format and reporting of this review adhered to the reporting Meta-analyses Of Observational Studies in Epidemiology (MOOSE) guidelines.[33] A comprehensive search of the PubMed, EMBASE, Web of Science, and China National Knowledge Infrastructure databases was conducted. The search strategy included the combination of the following terms to identify relevant articles: (1) "Winter Olympic Games" OR "Olympic Winter Games" OR "Winter Olympics", (2) "injur*" OR "pain*", (3) "epidemiology" OR "epidemiologic" OR "epidemiological" OR "survey" OR "statistics" OR "incidence" OR "incidences", (4) (1 AND 2 AND 3).

After removing duplicates and reprints, titles and abstracts were screened for suitability. Full-text articles were retrieved to determine inclusion or exclusion and reduce selection and recall biases. Thus, review articles, retrospective studies, single or multiple case reports, and case series were excluded.

### Selection Criteria

The studies that met the following criteria were included in this review[9,28,29,36]:

1. Reported injury epidemiology in an observed sample.
2. Reported the rate of sports injuries in a sample investigated during the Winter Olympics, or provided sufficient data from which these figures could be calculated. No restrictions were placed on athlete age, sex, or competitive level.

Any studies that met the following criteria were excluded:

1. Investigated injuries in non-Winter Olympics events, such as the youth Olympics, summer Olympics, or Paralympic Games.
2. Conference papers, dissertation papers, review papers, case papers, and nonfull-text articles.
3. Reported about social science, public health, or medical services.
4. Included spectator and workforce injury/illness information.
5. Covered other games in addition to the Winter Olympic Games.
6. Not in English or Chinese.

The full text of articles that were eligible were retrieved and evaluated by 2 reviewers (Y.Wu and R.D.), both with a master's degree in sports rehabilitation. Any disagreements between the reviewers were resolved by a third reviewer (Y.Wenqiang), who holds a master's degree in sports medicine.

### Assessment of Study Quality

The Critical Appraisal Skills Programme (CASP) was used to assess study quality.[42] The CASP includes 12 questions and is commonly used to assess the quality of observational studies (case-control, cohort studies, and case series). For case series, questions 7, 8, and 12, which pertain specifically to the incidence rates reported in each study, were excluded.

### Data Extraction

The data extracted included study characteristics (eg, author, published year, and number of sample) and injury characteristics (eg, sport, number of sports injuries, incidence of injury, injury location, injury types, injury severity, and mechanism of injury). The reported injury rates were extracted and converted to an injury incidence rate (IIR; reported as a percentage) per 100 player-athletes using the following formula[7,40]:

$$\text{IIR} = \frac{\text{Number of injuries over a specified time}}{\text{Number of all included samples during exposure time}} \times 100$$

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TABLE 1
Study Characteristics

| Lead Author (Year Published) | Olympic Venue; Year | Sample Size | No. of injuries |
|---|---|---|---|
| Soligard (2019)[30] | Pyeongchang, South Korea; 2018 | 2914 | 376 |
| Soligard (2015)[31] | Sochi, Russia; 2014 | 2788 | 391 |
| Engebretsen (2010)[13] | Vancouver, Canada; 2010 | 2567 | 287 |
| Ekeland (1996)[11] | Lillehammer, Norway; 1994 | 555 | 3 |
| Total | - | 8824 | 1057 |

All data were extracted using Microsoft Excel (Version 2310; Build 16.0.16924.20054). In case of any unclear or missing data, the authors of that study were contacted by email for clarification.

## Statistical Analysis

Both qualitative and quantitative analyses were performed. Appropriate tables, diagrams, and effects models were constructed to analyze the Winter Olympics injury data using Review Manager Version 5.3 software (The Cochrane Collaboration), adopting single-group meta-analysis, and calculating the combined odds ratio and the 95% confidence interval. Subgroups analysis was performed according to the different sports, injury locations, and injury types.

Heterogeneity was assessed using the $I^2$ test, which quantifies the proportion of the observed variance attributable to the variance in true effects rather than to sampling error.[4] When the $I^2$ was <50%, heterogeneity was considered low, and the fixed-effects model was used for the meta-analysis. When the $I^2$ was $\geq$50%, heterogeneity was considered high, and the random-effects model was used. If the IIR was too low, a logarithmic transformation was performed on the injury rate.

## RESULTS

Overall, 168 articles were identified using the search strategy outlined in Figure 1. After removal of duplicates and exclusion of articles based on the full-text review, 4 studies were included in the meta-analysis (Table 1).[11,13,30,31]

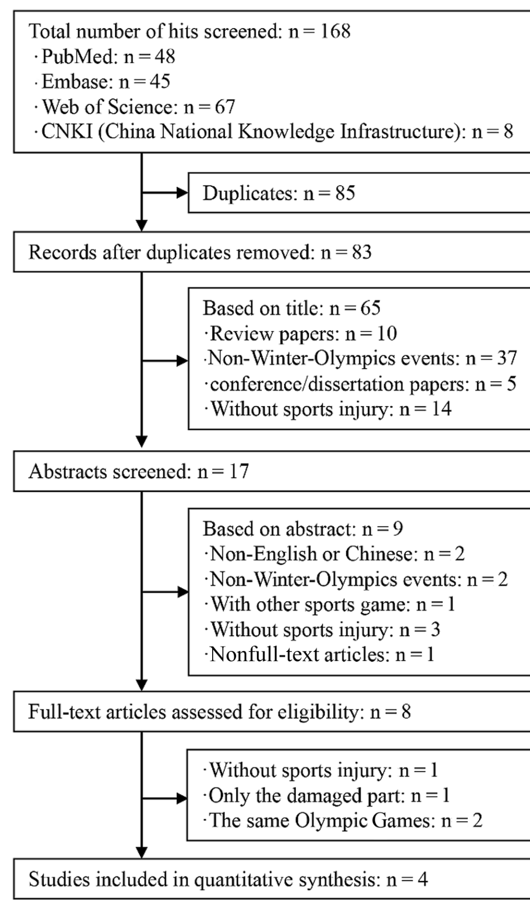


**Figure 1.** Flowchart of the process and rationale illustrating the inclusion and exclusion criteria used in the systematic review.

## CASP Assessment

The results of the CASP assessment are presented in Table 2. The findings exclude questions 7, 8 and 12, which pertain specifically to the incidence rates reported in each study. The quality of the included studies was high.

## Injury Incidence

The 4 included studies comprised 8824 athletes, 1057 of whom had injuries. The overall IIR in the Winter Olympics was 9.6% (95% CI, 0.82%-18.37%; $I^2$ = 99%).

## IIR According to Sport

The Winter Olympics sports were divided into ice sports (bobsled, skating, ice hockey, and curling) and snow sports (alpine skiing, freestyle skiing, snowboarding, and Nordic events); IIRs by sport are listed in Table 3. Only 1 study reported the injury rate for alpine skiing.[11] In total, the IIRs of ice sports and snow sports were 12.6% and 11.3%, respectively. The IIR for ice sports was higher than that for snow sports, although this difference was not statistically significant ($P$ > .05). In addition, the 3 sports with the highest IIRs were snow sports: snowboard-cross in

TABLE 2
Results of CASP Checklist for Cohort Studies[a]

| | CASP Questions[b] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Study | Q1 | Q2 | Q3 | Q4 | Q5(A) | Q5(B) | Q6(A) | Q6(B) | Q9 | Q10 | Q11 |
| Soligard[30] | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Soligard[31] | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Engebretsen[13] | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Ekeland[11] | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes |

[a]CASP, Critical Appraisal Skills Programme.
[b]CASP questions: Q1, Did the study address a clearly focused issue? Q2, Was the cohort recruited in an acceptable way? Q3, Was the exposure accurately measured to minimize bias? Q4, Was the outcome accurately measured to minimize bias? Q5, (A) Have the authors identified all important confounding factors? (B) Have they taken account of the confounding factors in the design and/or analysis? Q6, (A) Was the follow-up of subjects complete enough? (B) Was the follow-up of subjects long enough? Q7, What are the results of this study? Q8, How precise are the results? Q9, Do you believe the results? Q10, Can the results be applied to the local population? Q11, Do the results of this study fit with other available evidence? Q12, What are the implications of this study for practice?

TABLE 3
IIR According to Sport[a]

| | Soligard[30] | | Soligard[31] | | Engebretsen[13] | | Ekeland[11] | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sport | Athl, n | Inj, n | Athl, n | Inj, n | Athl, n | Inj, n | Athl, n | Inj, n | Athl, n | Inj, n | IIR, % |
| Ice sports | 1380 | 188 | 1324 | 146 | 1289 | 169 | NR | NR | 3993 | 503 | 12.6 |
| Bobsled | 323 | 45 | 326 | 45 | 314 | 37 | NR | NR | 963 | 127 | 13.2 |
| Bobsled | 163 | 28 | 171 | 31 | 159 | 32 | NR | NR | 493 | 91 | 18.5 |
| Luge | 110 | 13 | 108 | 9 | 108 | 2 | NR | NR | 326 | 24 | 7.4 |
| Skeleton | 50 | 4 | 47 | 5 | 47 | 3 | NR | NR | 144 | 12 | 8.3 |
| Skating | 450 | 55 | 432 | 37 | 431 | 46 | NR | NR | 1313 | 138 | 10.5 |
| Figure skating | 153 | 15 | 149 | 20 | 146 | 21 | NR | NR | 448 | 56 | 12.5 |
| Short-track | 113 | 17 | 106 | 9 | 109 | 20 | NR | NR | 328 | 46 | 14.0 |
| Speed skating | 184 | 23 | 177 | 8 | 176 | 5 | NR | NR | 537 | 36 | 6.7 |
| Ice hockey | 495 | 79 | 466 | 52 | 444 | 82 | NR | NR | 1405 | 213 | 15.2 |
| Curling | 112 | 9 | 100 | 12 | 100 | 4 | NR | NR | 312 | 25 | 8.0 |
| Snow sports | 1601 | 190 | 1464 | 242 | 1278 | 118 | 555 | 3 | 4898 | 553 | 11.3 |
| Alpine skiing | 322 | 57 | 314 | 65 | 308 | 46 | 555 | 3 | 1499 | 171 | 11.4 |
| Freestyle skiing | 272 | 50 | 262 | 72 | 172 | 23 | NR | NR | 706 | 145 | 20.5 |
| Aerials | 50 | 10 | 43 | 21 | 47 | 9 | NR | NR | 140 | 40 | 28.6 |
| Halfpipe | 51 | 14 | 51 | 13 | NR | NR | NR | NR | 102 | 27 | 26.5 |
| Moguls | 60 | 3 | 57 | 14 | 57 | 1 | NR | NR | 174 | 18 | 10.3 |
| Ski cross | 57 | 14 | 59 | 8 | 68 | 13 | NR | NR | 184 | 35 | 19.0 |
| Slopestyle | 54 | 9 | 52 | 16 | NR | NR | NR | NR | 106 | 25 | 23.6 |
| Snowboarding | 321 | 51 | 237 | 59 | 185 | 33 | NR | NR | 743 | 143 | 19.3 |
| Halfpipe | 54 | 8 | 66 | 12 | 69 | 9 | NR | NR | 189 | 29 | 15.3 |
| Slopestyle | 66 | 14 | 46 | 17 | NR | NR | NR | NR | 112 | 31 | 27.7 |
| Snowboard cross | 70 | 18 | 61 | 21 | 57 | 20 | NR | NR | 188 | 59 | 31.4 |
| Parallel slalom | 62 | 3 | 64 | 9 | 59 | 4 | NR | NR | 185 | 16 | 8.7 |
| Big air | 69 | 8 | NR | NR | NR | NR | NR | NR | 69 | 8 | 11.6 |
| Nordic events | 686 | 32 | 651 | 46 | 613 | 16 | NR | NR | 1950 | 94 | 4.8 |
| Biathlon | 219 | 6 | 204 | 14 | 202 | 3 | NR | NR | 625 | 23 | 3.7 |
| Cross-country | 311 | 18 | 297 | 23 | 292 | 9 | NR | NR | 900 | 50 | 5.6 |
| Nordic combined | 55 | 1 | 54 | 2 | 52 | 1 | NR | NR | 161 | 4 | 2.5 |
| Ski jumping | 101 | 7 | 96 | 7 | 67 | 3 | NR | NR | 264 | 17 | 6.4 |
| Total | 2914 | 376 | 2788 | 391 | 2567 | 287 | 555 | 3 | 8824 | 1057 | 12.0 |

[a]Athl, athletes; Inj, injuries; IIR, injury incidence rate; NR, not reported.

TABLE 4
IIR According to Injury Location[a]

| Location | Soligard[30] | Soligard[31] | Engebretsen[13] | Ekeland[11] | Total IIR (95% CI) |
|---|---|---|---|---|---|
| Head and neck | 16.0 | 19.7 | 20.7 | 33.3 | 18.6 (18.2-19.1) |
| Face (including eyes, ears, nose) | 5.7 | 1.6 | 4.5 | NR | 5.3 (5.1-5.5) |
| Head | 6.3 | 18.0 | 10.5 | 33.3 | 10.6 (9.4-11.9) |
| Cervical spine/neck | 4.1 | NR | 5.6 | NR | 4.8 (4.5-5.1) |
| Trunk | 17.4 | 14.8 | 16.5 | NR | 17.0 (16.9-17.1) |
| Thoracic spine/upper back | 3.3 | 1.6 | 3.5 | NR | 3.3 (3.3-3.4) |
| Lumbar spine/lower back | 7.3 | 8.2 | 5.6 | NR | 6.8 (6.6-7.1) |
| Chest/ribs | 1.6 | 3.3 | 1.8 | NR | 1.7 (1.6-1.8) |
| Abdomen | 0.3 | NR | 1.8 | NR | 1.5 (0.7-2.2) |
| Pelvis/sacrum/buttock | 4.9 | 1.6 | 3.9 | NR | 4.5 (4.4-4.7) |
| Upper limbs | 22.0 | 16.4 | 21.4 | NR | 21.7 (21.7-21.8) |
| Shoulder/clavicle | 7.1 | 4.9 | 5.3 | NR | 6.5 (6.2-6.7) |
| Upper arm | 1.6 | NR | 1.1 | NR | 1.5 (1.3-1.7) |
| Elbow | 3.3 | 3.3 | 3.2 | NR | 3.2 (3.2-3.2) |
| Forearm | 1.6 | 1.6 | 1.1 | NR | 1.5 (1.3-1.7) |
| Wrist | NR | 3.3 | 4.9 | NR | 4.9 (4.8-4.9) |
| Hand/finger | 8.4 | 3.3 | 6.0 | NR | 7.7 (7.3-8.0) |
| Lower limbs | 44.6 | 49.2 | 41.4 | 66.7 | 44.0 (43.6-44.3) |
| Hip/groin | 6.5 | 1.6 | 4.9 | NR | 6.0 (5.8-6.2) |
| Knee | 14.4 | 41.0 | 13.7 | 33.3 | 20.0 (17.9-22.0) |
| Thigh | 4.6 | 1.6 | 7.0 | NR | 5.7 (5.3-6.1) |
| Lower leg | 3.3 | NR | 6.3 | NR | 4.9 (4.3-5.5) |
| Achilles tendon | 1.4 | 1.6 | 1.1 | NR | 1.3 (1.2-1.4) |
| Ankle | 9.2 | 1.6 | 5.6 | NR | 8.2 (7.8-8.7) |
| Foot/toe | 5.2 | 1.6 | 2.8 | 33.3 | 5.4 (3.3-7.5) |
| Total | 7.1 | 20.2 | 6.7 | 4.8 | 7.1 (2.3-11.9) |

[a]Data are reported in percentages. IIR, injury incidence rate; NR, not reported.

snowboarding (31.4%), aerials in freestyle skiing (28.6%), and slopestyle in snowboarding (27.7%).

## IIR According to Injury Location

Among the 4 studies included, 1 reported the injury location data on just 65 athletes with severe injuries,[13] and 1 reported the injury location of only 3 athletes.[11]

The total IIR for all locations in the body was 7.1% (95% CI, 2.3%-11.9%; $I^2 = 0\%$). The lower limb (IIR = 44.0%; 95% CI, 43.6%-44.3%) was the most frequently injured location. The knee was the most commonly injured part (IIR = 20.0%; 95% CI, 17.9%-22.0%). This was followed by the head (IIR = 10.6%; 95% CI, 9.4%-11.9%). The third was the ankle (IIR = 8.2%; 95% CI 7.8%-8.7%). Table 4 lists the pooled IIRs by location.

## IIR According to Injury Type

Two studies reported the type of injury,[30,31] 1 recording the injury type data on just 65 athletes with severe injuries,[13] and 1 recording nothing about the injury type.[11] Of all the injury types, contusion/hematoma/bruising was the most common (IIR = 29.9%; 95% CI, 29.7%-30.0%), followed by sprains (dislocation, subluxation, instability, ligamentous, rupture) (IIR = 21.9%, 95% CI, 21.4%-22.3%) and strains (muscle rupture, tear, tendon rupture) (IIR = 11.3%, 95% CI, 11.0%-11.6%) (Table 5).

## Injury Severity

Injury severity was reported in 3 studies,[13,30,31] while the remaining study did not explicitly describe severity.[11] The severity of injury, as per the statement, ranged from slight (no time loss from sport), minimal (1-3 days absence), mild (4-7 days absence), moderate (8-28 days absence), and severe (more than 28 days absence).[42] In this analysis, 64.5% of athletes had no time loss from sport after injury, 24.0% lost <7 days, and 11.5% lost >7 days.

Three studies reported time-loss data in different sports.[13,30,31] Among the athletes with time lost to injury, the relationship between injury severity and injury rate according to sport is given in Table 6. The rate of time loss after injury in snow sports was higher than that in ice sports (65.4% vs 30.5%, $P < .05$), and the top 3 sports with the highest injury time loss were snowboarding (20.5%), freestyle skiing (18.9%), and alpine skiing (17.3%).

## Injury Mechanism

Three studies described the injury mechanism,[13,30,31] classified as contact or noncontact. One study described only

TABLE 5
IIR According to Injury Type[a]

| Injury Type | Soligard[30] | Soligard[31] | Engebretsen[13] | Ekeland[11] | Total IIR (95% CI) |
|---|---|---|---|---|---|
| Concussion | 4.4 | 15.9 | 7.1 | 33.3 | 6.5 (5.8-7.1) |
| Fracture (trauma, stress, other bone injuries) | 7.0 | 21.7 | 6.7 | 33.3 | 7.9 (7.3-8.5) |
| Sprain (dislocation, subluxation, instability, ligamentous, rupture) | 22.7 | 39.1 | 18.1 | 33.3 | 21.9 (21.4-22.3) |
| Strain (muscle rupture, tear, tendon rupture) | 10.2 | 5.8 | 12.8 | NR | 11.3 (11.0-11.6) |
| Meniscus, cartilage | 2.0 | NR | 1.4 | NR | 1.8 (1.6-2.0) |
| Contusion, hematoma, bruise | 31.1 | 8.7 | 28.4 | NR | 29.9 (29.7-30.0) |
| Tendinosis, tendinopathy | 0.3 | 1.4 | 5.7 | NR | 5.2 (4.4-6.0) |
| Arthritis, synovitis, bursitis | 1.2 | NR | 1.1 | NR | 1.1 (1.1-1.2) |
| Impingement | 1.7 | NR | 1.1 | NR | 1.5 (1.3-1.8) |
| Laceration, abrasion, skin lesion | 10.8 | NR | 8.9 | NR | 10.1 (9.9-10.3) |
| Dental injury, broken tooth | 1.2 | NR | 1.1 | NR | 1.1 (1.1-1.2) |
| Muscle cramps, spasm | 3.8 | 2.9 | 2.8 | NR | 3.5 (3.3-3.6) |
| Other (including nerve, spinal cord, fasciitis) | 3.8 | 4.3 | 5.0 | NR | 4.3 (4.1-4.6) |

[a]Data are reported in percentages. IIR, injury incidence rate; NR, not reported.

TABLE 6
Injury Severity (Time Loss) According to Sport[a]

| | Soligard[30] | | Soligard[31] | | Engebretsen[13] | |
|---|---|---|---|---|---|---|
| Sport | ≥1 day | >7 days | ≥1 day | >7 days | Time Loss | Total Time Loss |
| Ice sports | 29.0 | 4.8 | 27.2 | 13.2 | 35.4 | 30.5 |
| Bobsled | 7.3 | 1.6 | 4.0 | 1.3 | 6.2 | 5.8 |
| Bobsled | 4.8 | NR | 3.3 | 1.3 | 4.6 | 4.2 |
| Luge | 1.6 | 1.6 | 0.7 | NR | NR | 0.8 |
| Skeleton | 0.8 | NR | NR | NR | 1.5 | 0.8 |
| Skating | 10.5 | 1.6 | 6.0 | 1.3 | 4.6 | 7.0 |
| Figure skating | 1.5 | NR | 1.3 | 0.7 | NR | 0.9 |
| Short-track | 3.0 | 0.8 | 2.6 | 0.7 | 3.1 | 2.9 |
| Speed skating | 5.3 | 0.8 | 2.0 | NR | 1.5 | 2.9 |
| Ice hockey | 11.3 | 1.6 | 11.6 | 9.9 | 24.6 | 15.8 |
| Curling | NR | NR | 0.7 | 0.7 | NR | 0.2 |
| Snow sports | 71.0 | 33.9 | 71.5 | 40.4 | 53.8 | 65.4 |
| Alpine skiing | 14.3 | 6.0 | 19.2 | 7.9 | 18.5 | 17.3 |
| Freestyle skiing | 25.0 | 12.9 | 22.5 | 15.2 | 9.2 | 18.9 |
| Aerials | 1.5 | NR | 4.0 | 2.6 | 3.1 | 2.9 |
| Halfpipe | 6.5 | 3.2 | 4.0 | 2.6 | NR | 3.5 |
| Moguls | 8.1 | 4.0 | 6.6 | 3.3 | 1.5 | 5.4 |
| Ski cross | 6.5 | 4.8 | 4.0 | 4.0 | 4.6 | 5.0 |
| Slopestyle | 2.4 | 0.8 | 4.0 | 2.6 | NR | 2.1 |
| Snowboarding | 25.0 | 14.5 | 17.9 | 11.3 | 18.5 | 20.5 |
| Halfpipe | 2.4 | 0.8 | 2.0 | 1.3 | 3.1 | 2.5 |
| Slopestyle | 7.3 | 4.8 | 7.9 | 3.3 | NR | 5.1 |
| Snowboard cross | 9.7 | 7.3 | 6.6 | 5.3 | 12.3 | 9.5 |
| Parallel slalom | 1.6 | NR | 1.3 | 1.3 | 3.1 | 2.0 |
| Big air | 4.0 | 1.6 | NR | NR | NR | 1.3 |
| Nordic events | 5.6 | NR | 11.9 | 6.0 | 7.7 | 8.4 |
| Biathlon | 0.8 | NR | 3.3 | 1.3 | 1.5 | 1.9 |
| Cross-country | 2.4 | NR | 4.6 | 2.0 | 3.1 | 3.4 |
| Nordic combined | NR | NR | 1.3 | 1.3 | NR | 0.4 |
| Ski jumping | 2.4 | NR | 2.6 | 1.3 | 3.1 | 2.7 |

[a]Data are reported in percentages. NR, not reported.

contact and noncontact injury rates.[11] The most common reported injury mechanism was noncontact injury (IIR = 63.6%; 95% CI, 62.9%-64.4%).

## DISCUSSION

The principal findings were that the overall incidence of injury during the Winter Olympic Games was 9.6%; the top 3 injury incidences were snowboard cross of snowboarding (31.4%), aerials of freestyle skiing (28.6%), and slopestyle of snowboarding (27.7%); the most common injury locations were the knees (20.0%); the most injuries were slight without time loss (64.5%); and the most were noncontact-related injuries (63.3%). This is the first systematic review to evaluate the characteristics of sports injuries of Winter Olympic Games athletes. This systematic review and meta-analysis aimed to investigate the prevalence, incidence, and profile of injuries, including sports with the highest number of injuries, as well as the body location, type of injury, severity of injury, and mechanism of injury in athletes.

### Injury Incidence

Our findings showed that the incidence of injury in Winter Olympic Games athletes was 9.6%. The overall injury rate throughout the Summer and Winter Olympic Games has remained fairly constant. The injury rates in Tokyo 2020, Rio de Janeiro 2016, London 2012, and Beijing 2008 were 9.1, 9.8, 11, and 9.6 per 100 athletes, respectively.[12,19,32] The rates in the recent Paralympic Winter Olympic Games were higher than those at the Winter Olympic games, at 19.8 and 23.8 per 100 athletes in Pyeongchang 2018 and Vancouver 2010.[7,28,39] This might have been due to a number of reasons. First, Olympic sports have the characteristics of requiring greater speeds, greater heights, and more intense competition than recreational sports. Second, the Olympic Games require higher physical fitness, and Paralympians find it more difficult to complete the sport and are more susceptible to injury. Third, the injury incidence may experience incidental variation as a result of factors such as the events included in the Olympic Games (eg, any new sports added), environmental factors, venue or track design, competition rules or changes in equipment, the manner of information recording, athlete awareness of injury protection, and the capability of medical services of transportation and treatment for injured athletes.[5,20,38]

### Injury Rates in Different Sports

Our hypothesis, that the injury rate of snow sports would be higher, was partially supported. Our results showed that the difference in IIR in ice-sports and snow sports was not significant, and the top 3 sports in terms of injury rates were snow sports, snowboard cross of snowboarding, aerials of freestyle skiing, and slopestyle of snowboarding. Some studies have identified a large variation among these different sports. The IOC Medical Commission had defined freestyle skiing and snowboard, super-G, speed skating, short-track, and ice hockey as high-risk sporting events.[3] Moreover, the International Ski Federation (FIS) World Cup reported snowboard cross and halfpipe, aerial and halfpipe skiing, and ski cross as having higher rates of injury.[15,35] The main reason for this high injury rate is that the sports involve more extreme performance and snow constructions.[35] Furthermore, the combination of speed and jumps seen in freestyle skiing and snowboarding may promote a risk-taking attitude for participants to stay at the top of their sport performance. In particular, jumping is the essence of the sport, and the judging criteria reward height and rotation.[16,21] Previous studies reported that the injury risk was lower among Nordic skiing athletes than that among alpine, freestyle, and snowboard athletes, as they are not exposed to icy surfaces, high speed, or spectacular jumps.[16,17,41] However, some studies have reported that athletes in every sport have the same risk of injury.[1,18]

### Injury Location

Our hypothesis that the most common injury location would be the lower extremity was largely supported. Our study showed that the knee, head, and ankle were the body parts injured most frequently among Winter Olympics athletes. Winter Olympics sports involve jumping and rotating movements at high speed. Especially when snow-sports athletes perform aerial maneuvers, they risk damaging their knee joints. Studies have shown that jumping promotes knee injuries in professional snowboarders.[2,22] Like ours, several studies have identified the knee as the most common site of injury.[26,27] Head injuries are reportedly frequent, while some studies have also identified head injuries as the second-most common injury location.[6,41] Although the FIS International Competition rules state that a helmet should be worn specifically for snowboarding or ski racing, the rate of injury to the head is high, especially during training.[8,35] The ankle is another area with a high injury rate.[19,23] Ankle sprain was a common prevalent diagnosis in sports injury[19]; this may be related to the jumping and lower limb stabilizing movements. This predisposes the ankle to injury. In many cases, knee, head, and ankle injuries result in long absence from training and competition. Thus, it is important for athletes to prevent sports injury.

### Injury Type, Severity, and Mechanism

Our hypothesis that contusion/hematoma/bruising would be the more common injury types was supported. Our findings indicated that the most common injury type was contusion/hematoma/bruising, sprain (dislocation, subluxation, instability, ligamentous, rupture), and strain (muscle rupture, tear, tendon rupture). This may be related to the movements performed during these sports, many of which involve torsional and shear force at high speed.

Moreover, injury rate is influenced by factors such as the field conditions, weather, and temperature.

Our hypothesis that most injuries would be associated with minimal time lost from sport was not supported. Our results indicated that the most common injury severity was slight. Our findings also indicated that most athletes would not lose time from sports after injury. However, all injuries, even those of minor severity without time loss, have the potential to be both participation-limiting and performance-inhibiting, and thus prevent athletes from possibly fulfilling their potential performance. The injury mechanism can affect the type and severity of the injury. Our study showed that most of the injuries were noncontact. This may because many athletes sustain chronic injury and are at a higher risk of injury. However, the type, severity, and mechanism of injuries in competition differed between different sports. Information regarding the injury severity, type, and mechanism are essential for setting targets for preventive, therapeutic, and rehabilitative strategies.

### Limitations

This study has several limitations. First, the low number of studies included in the meta-analytic review limits the generalizability of our results. The varying injury definitions, duration of data collection, and methodological, language differences as well as the same Olympic games in different studies resulted in only 4 studies being suitable. Furthermore, some included studies did not provide all of the detailed information used to calculate these figures, such as the number of injuries and exposures by sex, the injury location and type in different sports, or the injury severity in different periods. At the same time, these injuries may be under-reported, because the athlete may not want to reveal injury for fear of being not cleared to compete. Finally, there was no subgroup of injury characteristics by sex and sport.

### Suggestions and Future Directions

We hope that the results of this study can help to provide data required for the development, application, and assessment of injury causation and prevention models. The IOC, National Olympic Committee, and International Sports Federation should strengthen the monitoring and protection of athletes to reduce the incidence of injuries. For example, researching the precise biomechanical factors involved in the injury mechanism and movement technology in large-scale competitions can help provide evidence-based injury prevention measures to every athlete. The comprehensive capacity of medical services needs to be enhanced to improve the professional quality of medical personnel, intervene with early rehabilitation, promote mental health, and improve the level of services. Future research should be combined with virtual simulation technology to explore whether adding virtual simulation training can reduce the injury incidence in difficult movements. At the same time, such advancements could also be adopted to benefit the general population.

## CONCLUSION

Snow-sports injuries were the most common in the Winter Olympic Games, and the 3 sports with the highest IIRs were snowboard cross of snowboarding, aerials of freestyle skiing, and slopestyle of snowboarding. The most common injury locations were the knee, head, and ankle. The most common injury types were contusion/hematoma/bruising, sprain, and strain. Most injuries were slight without time loss from sport, and the most were noncontact-related injuries. Our results can inform both the planning and provision of health care, prevention, treatment, and rehabilitation for athletes in Winter Olympics sports.

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