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Comparison of the incidence, mechanisms, and risk factors of anterior cruciate ligament injury during rotational knee trauma in skiers and snowboarders. A Perspective of Recent Literature.

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Abstract

Introduction

Knee injuries are among the most common and clinically significant injuries in winter sports, particularly in alpine skiing and snowboarding. Differences in sport-specific biomechanics and equipment constraints are thought to influence both injury incidence and patterns.

Methods

This study is a literature review aimed at analyzing and comparing the incidence, mechanisms, and risk factors of rotational knee injuries in individuals participating in skiing and snowboarding. The review was conducted based on current scientific reports in the fields of orthopedics and sports medicine, with particular emphasis on anterior cruciate ligament (ACL) injuries. The analysis was performed using scientific publications available in electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar. Articles published primarily between 2000 and 2025 were included, with particular emphasis on the most recent reports from 2020 to 2026. The literature search was conducted using the following keywords: “knee injuries skiing”, “snowboarding injuries knee”, “ACL injury skiing vs snowboarding”, “anterior cruciate ligament winter sports”, “risk factors knee injuries skiing”. No studies are excluded from the review.

Aim of the study

The aim of this study is to compare the incidence, mechanisms, and risk factors of rotational knee injuries in individuals participating in skiing and snowboarding. Understanding the differences in injury mechanisms and identifying associated risk factors are essential for the development of effective prevention strategies and optimization of treatment. A comparative analysis of rotational knee injuries in skiers and snowboarders enables a better understanding of the specific characteristics of

these disciplines and may contribute to reducing the incidence of such injuries in the future.

Conclusion

Skiing is associated with a higher risk of rotational knee injuries compared to snowboarding. The anterior cruciate ligament (ACL) is the most frequently injured structure. Differences in injury mechanisms indicate the need for distinct preventive strategies in the two disciplines.

Keywords

“knee injuries skiing”, “snowboarding injuries knee”, “ACL injury skiing vs snowboarding”, “anterior cruciate ligament winter sports”, “risk factors knee injuries skiing”.

Introduction and background

Musculoskeletal injuries constitute a significant problem in contemporary medicine, particularly in the context of the growing popularity of physical activity and recreational sports. Among these, winter sports—such as skiing and snowboarding—occupy a prominent place, attracting millions of participants worldwide each year. Despite their numerous health benefits, these activities are also associated with a substantial risk of injury, especially involving the musculoskeletal system [1,2]. Epidemiological studies emphasize that although the overall incidence of injuries in both disciplines is comparable, their nature and anatomical distribution differ significantly.

One of the joints most frequently injured during participation in winter sports is the knee joint, which plays a crucial role in stabilization and load transmission during movement. Structures responsible for knee stability, including the ligaments and menisci, are particularly susceptible to injury. Among these, the anterior cruciate ligament (ACL)—which is responsible for controlling anterior tibial translation and rotation relative to the femur—is most commonly affected. Such injuries often have serious clinical consequences, requiring prolonged treatment and rehabilitation, and may in some cases lead to permanent impairment of physical function [3,5].

The nature and incidence of knee injuries vary depending on the sport. Alpine skiing is associated with substantial forces acting on the lower limb, resulting from load transmission through rigid ski boots and bindings, which predisposes to rotational knee injuries, particularly those involving a torsional mechanism [4,11].

In contrast, snowboarding—due to the characteristic body positioning and immobilization of both feet on a single board—is associated with a different movement biomechanics, which translates

into a distinct injury profile. In this discipline, injuries to the upper extremities, particularly the wrist and shoulder girdle, are more commonly observed. Nevertheless, knee joint injuries also constitute a significant clinical concern [7,12].

Recent studies indicate that the risk of anterior cruciate ligament (ACL) injuries in skiing depends not only on technique but also on environmental factors, such as snow conditions and terrain characteristics [13]. Thomas W. Florenes et al. [6] analyzed injuries among World Cup athletes, demonstrating that alpine skiing is associated with a high risk of injury, with the knee joint being one of the most frequently affected structures. This finding underscores its particular susceptibility to injury in this discipline, even among elite professionals.

At the same time, increasing attention is being paid to injuries in snowboarding; however, the number of studies in this group remains limited compared with skiing, highlighting the need for further investigation [14]. Contemporary systematic reviews also point to the multifactorial nature of ACL injury risk, encompassing both intrinsic factors (biomechanical and anatomical) and extrinsic factors (equipment and environmental conditions) [17].

Additionally, the role of anatomical and individual variables—such as lower limb asymmetry and impaired neuromuscular control—is emphasized, as these may further increase susceptibility to ACL injury [8,15].

The literature indicates that knee injuries may account for as much as 30–40% of all skiing-related injuries, making them one of the most important clinical problems in this discipline [3,5]. In snowboarding, this proportion is lower; however, knee injuries still occur and should be considered in comparative analyses [7].

ACL injuries represent one of the most serious consequences of sports-related trauma in skiing. Numerous studies have shown that they account for approximately 15–20% of all skiing injuries, and their occurrence is often associated with prolonged treatment and rehabilitation [4,5]. A characteristic feature of these injuries is their non-contact mechanism, meaning that they occur without the involvement of another athlete. They most commonly result from a combination of rotational forces, knee valgus stress, and sudden deceleration, leading to forces that exceed the physiological tolerance of the ligament.

In snowboarding, ACL injuries are observed less frequently, which is related to differences in movement biomechanics and lower limb positioning; nevertheless, they remain a significant concern, particularly in cases of high-speed falls or during aerial maneuvers [7,14].

An important aspect of the analysis concerns differences in injury mechanisms between skiing and snowboarding. In skiing, rotational forces acting on the knee joint play a predominant role, amplified by rigid ski boots and binding systems. The literature describes characteristic injury mechanisms, such as the so-called “phantom foot,” in which tibial rotation occurs with the foot fixed, as well as the “boot-induced ACL injury” mechanism [4,11]. Such situations generate substantial forces acting on the knee ligaments, thereby increasing the risk of injury.

In snowboarding, by contrast, both lower limbs are fixed to a single board, which limits independent leg movement and alters load transmission. Knee injuries in this discipline most

commonly result from falls onto flexed lower limbs, excessive loading during landings after jumps, or sudden changes in direction [7].

The analyzed literature also highlights the importance of risk factors that may increase the likelihood of rotational knee injuries. These factors can be divided into intrinsic and extrinsic categories. Intrinsic factors include sex, level of physical fitness, neuromuscular control, and previous injuries. It has been shown that women are at a higher risk of ACL injury, which is attributed to anatomical and biomechanical differences [3].

The level of athletic experience is also important—beginners are more frequently injured due to insufficient technique and lack of experience. It should also be emphasized that an aggressive skiing style and high speed significantly increase the risk of knee injuries, including ACL tears and complex injuries involving osseous structures [9].

Extrinsic factors include environmental conditions and sports equipment. Recent studies indicate that snow quality, slope gradient, and weather conditions may significantly influence injury risk [13]. The type and fit of equipment also play an important role—improperly selected or rented equipment has been shown to increase the risk of knee injuries.

In skiing, the correct adjustment of binding release settings is of particular importance; if improperly calibrated, the bindings may fail to release during a fall, resulting in direct transmission of forces to the knee joint [11].

Materials and methods

This study was designed as a narrative literature review with elements of structured systematic approach. The aim was to synthesize and critically evaluate the current scientific evidence regarding knee sprain injuries in winter sports, with particular emphasis on alpine skiing and snowboarding. A comprehensive search of the literature was performed using the following electronic databases: PubMed Scopus, Web of Science and Google Scholar. In addition, manual screening of reference lists from relevant articles was conducted to identify further eligible publications.

The search strategy was based on combinations of keywords including: “knee injuries skiing”, "snowboarding injuries knee”, “ACL injury skiing vs snowboarding”, “anterior cruciate ligament winter sports”, “risk factors knee injuries skiing”. The search was limited to articles published between 2000-2026, with priority given to recent high-impact studies.

Studies were included if they were peer-reviewed original articles, systematic reviews, or epidemiological studies focusing on knee injuries in alpine skiing or snowboarding. Eligible publications had to report on injury incidence, anatomical location, mechanisms of injury, or risk factors, and be avaliable in full text in English. Case reports, expert opinions without original data, non-English publications, and abstracts without full-text availability were excluded from the analysis.

Results

The nature and incidence of knee injuries vary depending on the sport. Alpine skiing is associated with substantial forces acting on the lower limb, resulting from load transmission through rigid ski boots and binding systems, which predisposes to rotational knee injuries, particularly those involving a torsional mechanism [4,11].

In contrast, snowboarding—due to the specific body positioning and immobilization of both feet on a single board—is characterized by a different movement biomechanics, which results in a distinct injury profile. In this discipline, upper limb injuries, particularly of the wrist and shoulder girdle, are more frequently observed. Nevertheless, knee joint injuries also remain a clinically relevant problem [7,12].

Recent studies indicate that the risk of anterior cruciate ligament (ACL) injury in skiing depends not only on skiing technique but also on environmental factors such as snow conditions and terrain characteristics [13]. At the same time, growing interest in snowboarding-related injuries has been observed; however, the number of studies in this population remains limited compared with skiing, highlighting the need for further research [14].

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In skiing, correct adjustment of binding release settings is of particular importance; if improperly calibrated, bindings may fail to release during a fall, resulting in direct transmission of forces to the knee joint [11]. The development of sports equipment technology, including the introduction of shorter carving skis, has also contributed to changes in injury mechanisms, increasing the proportion of ACL injuries relative to other ligamentous structures. This shift is associated with greater rotational forces transmitted through the knee joint [10].

A comparison of both disciplines clearly indicates that skiing is associated with a higher risk of rotational knee injuries, particularly ACL tears. This is primarily due to greater forces acting on the lower limb and more complex movement biomechanics. Snowboarding, although also associated with injury risk, is characterized by a different injury profile, with a predominance of upper limb injuries and a lower incidence of knee injuries [1,7].

Table 1. Overview of selected studies on incidence, mechanisms, and risk factors of knee injuries in alpine skiing and snowboarding.

Author (year)	Study type	Population	Key findings	Main conclusion
Fiorenes et al. (2009) [6]	Cohort study	World Cup alpine skiers	High incidence of lower limb injuries; knee is most frequently injured region	Alpine skiing at elite level is associated with high knee injury risk
Kim et al. (2012) [7]	Epidemiological study	Skiers vs snowboarders	Skiing shows higher knee injury rates; snowboarding shows higher upper limb injury rates	Distinct injury profiles between skiing and snowboarding

Ruedl et al. (2022) [3]	Systematic review	Recreational skiers	ACL injuries associated with sex, skill level, and environmental conditions	ACL injury is multifactorial in origin
Sundberg et al. (2025) [18]	Systematic review	Winter sport athletes	Non-contact ACL mechanisms dominate (valgus + rotation + anterior tibial translation)	Skiing has characteristic non-contact ACL mechanisms
KSSTA review (2025) [19]	Systematic review	Mixed populations	Equipment (boots, bindings) significantly affects knee loading	Skiing represents equipment-induced injury mechanism
Epidemiological pooled data (2025) [20]	Meta-analysis	Ski populations	ACL accounts for ~30%-40% of knee injuries	ACL is the leading severe injury in skiing
Biomechanical studies (2024-2025) [21]	Laboratory/field studies	Recreational skiers	Phantom foot and slip-catch mechanisms consistently observed	Mechanisms are reproducible and well defined
Snowboarding review (2023-2025) [25]	Systematic review	Snowboarders	Lower knee injury incidence; more fall-related injuries	Snowboarding has lower ACL injury risk

The presented table summarizes key studies investigating knee injuries in alpine skiing and snowboarding. The included publications comprise epidemiological studies, systematic reviews, and biomechanical analyses, allowing for a comprehensive, multi-dimensional assessment of knee injury patterns in winter sports.

Overall, the synthesized evidence consistently demonstrates that alpine skiing is associated with a higher incidence of knee injuries compared to snowboarding, with the anterior cruciate ligament being the most frequently affected structure. Across the reviewed studies, non-contact injury mechanisms are predominantly reported, including well-characterized patterns such as the “phantom foot” and “slip-catch” mechanisms, which involve combined rotational loading, dynamic valgus collapse, and anterior tibial translation.

In addition, the findings highlight the multifactorial nature of knee injuries in skiing, with intrinsic factors (e.g., sex, skill level) and extrinsic factors (e.g., snow conditions, speed, and equipment configuration) contributing significantly to injury risk. In contrast, snowboarding demonstrates a distinct injury profile characterized by a lower incidence of knee injuries and a higher proportion

of upper extremity trauma, reflecting fundamental biomechanical differences between the two disciplines.

In summary, the data presented in the table reinforce the concept that knee injuries in winter sports are highly sport-specific and result from complex interactions between biomechanical loading patterns, environmental conditions, and equipment-related factors.

Discussion

In summary, the analysis of available studies indicates that rotational knee injuries constitute a significant problem in winter sports, particularly in alpine skiing. The anterior cruciate ligament (ACL) is the most frequently injured structure, and the injury mechanism is most often non-contact in nature, resulting from rotational and valgus forces.

Differences in movement biomechanics between skiing and snowboarding translate into distinct injury profiles, highlighting the importance of an individualized approach to both prevention and treatment in these disciplines. Moreover, studies involving elite athletes indicate that return to activity after ACL injury is associated with a substantial risk of reinjury and difficulties in regaining full sports performance, emphasizing the importance of appropriate rehabilitation and functional assessment prior to return to sport [15,16].

It should be noted, however, that available data on snowboarders are less extensive and often based on smaller study populations, which limits direct comparison with skiing. A research gap remains evident in the current literature, particularly regarding recreational-level knee injuries in snowboarding.

It should also be emphasized that the interaction between intrinsic and extrinsic factors is dynamic and depends on the specific conditions on the slope, which makes it difficult to clearly determine their relative contribution to injury risk.

The literature analysis also highlights important methodological limitations of the available studies. A large proportion of publications are retrospective or observational in nature, which limits the ability to draw causal inferences. Furthermore, the lack of standardization in injury definitions and classification methods complicates comparisons between studies. Differences in study populations (competitive athletes versus recreational participants) further hinder data interpretation and limit the generalizability of findings to the broader skiing and snowboarding population.

From a clinical perspective, the findings have important implications. They highlight the need to develop targeted preventive strategies tailored to the specific characteristics of each discipline. In skiing, particular emphasis should be placed on neuromuscular control training programs and proper equipment adjustment, whereas in snowboarding, education regarding fall techniques and the reduction of overload forces is especially important.

At the same time, the increasing incidence of ACL injuries underscores the need for further research aimed at optimizing both prevention and treatment strategies, including return-to-sport protocols.

In conclusion, despite considerable progress in understanding knee injury mechanisms in winter sports, important knowledge gaps remain, particularly in relation to snowboarding and the interaction between biomechanical and environmental factors. Future studies should focus on prospective designs and the use of advanced biomechanical assessment methods, which may contribute to a more precise understanding of injury mechanisms and the development of more effective preventive strategies.

Conclusions

Alpine skiing demonstrates a consistently higher incidence of knee sprain injuries compared to snowboarding, with the ACL representing the predominant structure affected. Injury etiology is primarily non-contact and reflects a multifactorial interplay between excessive rotational torque, dynamic knee valgus, anterior tibial translation, and equipment-related constraints.

Current evidence suggests that sport-specific biomechanics, particularly the dissociation between lower limb motion and equipment-induced loading patterns, play a critical role in injury propagation. However, heterogeneity in study design, injury definitions, and population characteristics limits cross-study comparability and the ability to establish causal inference.

Future research should prioritize prospective, high-resolution biomechanical analyses and standardized injury reporting frameworks, particularly in underrepresented populations such as recreational snowboarders. From a clinical and preventive perspective, interventions targeting neuromuscular control, movement pattern optimization, and equipment calibration may represent the most effective strategies for reducing the burden of knee injuries in winter sports.

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