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Injuries in elite and recreational snowboarders

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ABSTRACT

Background The relatively young sport of snowboarding exhibits high injury rates. The current efforts to characterise the injury pattern of snowboarders focus largely on the general snowboard population and upper extremity injuries, the most common injury site in snowboarders as a whole.

Methods In an effort to describe the current published information available on snowboarding injuries in the elite-level population, a literature search was performed and the articles related to snowboarding injuries were analysed. Additionally, the literature pertaining to biomechanical analyses of injury and injury prevention was included.

Results Studies rarely stratify the snowboarders by skill level, a classification which has a profound effect on the riding activities of snowboarders and the resultant injury patterns. Elite-level snowboarders are often injured when performing difficult manoeuvres at high velocities and with amplified levels of force to the lower limbs. Consequently, elite-level snowboarders suffer from injuries that are of higher severity and have decidedly greater lower extremity injury rates. Conversely, injuries to the upper extremities are decreased in the elite snowboarders. Furthermore, little has been published regarding the biomechanical analyses and injury prevention for the protection of the lower extremities in snowboarding.

Conclusions Snowboarding continues to evolve as a sport. This includes a steady progression in the degree of difficulty of the manoeuvres conducted by athletes and an increase in the number of snowboarders attempting such manoeuvres. The injury patterns across the skill levels are markedly different, and it is imperative that the research directed towards understanding the disparate lower extremity injury pattern of elite-level snowboarders is increased.

INTRODUCTION

The sport of snowboarding has seen a rapid growth throughout the last several decades and today it is one of the most popular winter sports.[1] An estimated 7.3 million people participated in snowboarding in the USA alone during the 2012/2013 season compared with 8.2 million skiers. Although initially banned from many resorts and only recognised as an Olympic event in 1998, snowboarding is now an established and popular event on the Olympic programme.[1] Injury rates have also evolved and grown with the sport, and currently, the snowboarders are more likely to injure themselves than the skiers.[2–10] Moreover, while the injury rates for skiing have largely stabilised, the injury rates for snowboarding are still increasing.[5 11]

Many epidemiological studies on snowboard injuries have identified the upper extremity, particularly wrist and head injuries, as the most prevalent among the snowboarding community.[2 4 5 7 11–24] However, there is evidence in the literature that these injuries are more prevalent in the beginners,[2 5 13 16–18 21 25] and that *experienced* snowboarders exhibit different injury patterns with increased injuries to the lower extremity.[9 26–28] The injury mechanisms for those at the beginner level are more related to isolated falls,[16 29 30] and preventative measures such as wrist guards and helmet use have been developed and proven to be effective.[6 31–37] In contrast, without a biomechanical understanding of the aetiology of the more complex lower extremity injuries that occur at the experienced level, it will be difficult to establish the preventative measures for this elite-level group.

This review article, tailored to the practicing team sports physician, will focus on skill-level-dependent injury patterns and injuries in the elite-level snowboarders. In addition, the current understanding and status of biomechanical approaches for the analysis of snowboard injury mechanisms will be described.

METHODS

A literature search was performed using the PubMed, MEDLINE database with the root word ‘snowboard’, including any variation thereof. The search resulted in 368 articles after all the non-English articles were excluded. The search was as broad as possible to capture any pertinent research, and due to the low number of search results, all abstracts were reviewed for relevance to the topic of snowboarding injury. Based on the abstract, 102 articles were reviewed in detail. Additional relevant articles were included from the reference sections of previously identified publications and ultimately resulting in a total of 77 articles included in this review.

Injury patterns in the general snowboard community

The literature on snowboarding injury is relatively sparse compared with the published articles available for its older counterpart, alpine skiing. However, as the sport has grown in popularity, there has also been an increased effort to characterise the incidence and the types of injuries that occur. Several metrics have been used to measure injury rates, which we denote in table 1. Injury rates, defined as the number of injuries per 1000 snowboard days, have been reported to be between 1.16 and 4.2/1000 and are two to three times

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Table 1 Injury Incidence in snowboarding and skiing

Citation (chronological)	Snowboarding	Skiing
Bladin *et al*[25]	4.2 injuries/1000 visits	–
Sasaki *et al*[2]	0.33% injury rate	0.11% injury rate
Machold *et al*[17]	10.6 injures/ 1000 snowboard days	–
Made *et al*[4]	3 injuries/1000 skier days	1 injury/1000 skier days
Hagel *et al*[38]	1.15 injuries/ 1000 participants 1.16 injuries/1000 outings	–
Xiang *et al*[22]	13.5 injuries/ 1000 participants*	–
Sakamoto *et al*[7]	175 injuries/ 100 000 lift tickets†	80 injuries/100 000 lift tickets
Kim *et al*[10]	345 mean days between injury	400 mean days between injury

*Includes only 18–24 age group.
†Average of two most recent time periods.

higher than those in skiers (table 1). Dissimilar methods of recording injury limit the ability to compare the injury incidence over time; however, it is clear that the injury rate for snowboarding is higher than that of skiing. Furthermore, the injury rates for snowboarders do not appear to be decreasing.[7] A distinct definition of injury is imperative; however, many studies encompassing the general snowboarding do not provide such a definition and simply include all injuries that were reported to a specified location, regardless of injury type or consequences of injury. There are also differences across the represented studies as to the method with which injuries were identified. It is important to recognise that there is an elevated potential for inaccuracy of reported injuries when using ski patrol reports as opposed to official physician diagnoses,[39] and our selected articles for the general snowboarding population make use of both methods. Moreover, the types of injuries that present to ski patrol could be inherently different than those that report directly to the hospital (eg, more severe injuries reported directly to the emergency room).[40]

Several prospective and retrospective epidemiological studies provide a broad snapshot of the methods for identifying and defining an injury for the general snowboarding community and the most common injuries for the general snowboarding community, which we have denoted in table 2. This table demonstrates the identified studies that specified injury locations as a percentage of total reported injuries, and the injury rates were averaged by the location. By our compilation, injuries to the upper extremity represent 45% of snowboarding injuries, which is the largest proportion of injury location. The lower extremities are injured half as often (23%), which is in direct contrast to the typical skiing injury pattern where the opposite has been observed.[2 3 7 11 14 22] Wrist injuries alone, mainly wrist fractures, are shown to be the most common upper extremity and overall injury.[2 3 8 14 16 22 36] Head, face and neck injuries, especially contusions and concussions, are also frequent.[4 5 17 41] While some have reported head injuries as more common among the snowboarders than the skiers,[5 10 22 38 41–44] the mean rates between the two sports appear to be equivalent based on our compilation. Average knee injury incidence is described as markedly lower for snowboarding when compared with skiing,[2 4 5 8 11 14 15 17 22] while ankle injuries are slightly more common in snowboarding and include both sprains and fractures.[2 4 5 8 11 14 15 22]

On the basis of the specific literature, falls, whether on the slopes or when landing from a jump, generate 80–90% of the injuries.[5 16 17 19 21 36 38] Collisions are relatively rare in snowboarding compared with skiing,[45] and constitute most of the remaining injuries.[5 16 17 21 36 38] Injuries when landing from jumps are more common in snowboarding than in skiing,[14 21] and when separated from isolated falls, account for approximately 25% of all injuries.[7 28]

Skill-level-dependent injury patterns

In surveys that encompass all snowboarders, an average of 50% identified themselves as 'novice' or 'beginner', 37% as 'intermediate' and 13% as 'advanced'.[2 4 5 16 25 29 35 46] The majority of participants in snowboarding are described as beginners who have had little to no professional instruction[2 25 46]; consequently, this group experiences a large share of the injuries.[8 11 19 21 25 35 47] However, these skill-level designations are not only self-reported but are inherently vague, and thus reduce the reliability and validity when interpreting studies. While the elite-level snowboarders as a group are more objectively identifiable in that they participate in high-level events and competitions, there are limited opportunities to observe them in this environment. Thus, when discussing the elite-level snowboarders in this article we can be more confident that they are experts, while noting that there is little published information available to describe this category.

The methodology for current studies involving the elite-level snowboarders is distinct from studies involving the larger snowboarding population, and is outlined in table 3. Instead of relying on ski patrol or hospital reports, studies involving elite snowboarders utilise either a prospective injury surveillance of competition seasons or events,[26 48] or retrospective interviews of athletes at the end of competition season.[9 26 27 49] A 2011 methodological study of World Cup injury reporting found that retrospective athlete interviews at the end of the season, as opposed to prospective medical team registration or prospective injury reports, was the most accurate method of recording injury for the World Cup setting.[50] Additionally, the current studies involving the elite snowboarders have much more specific injury definitions delineated in the methodology than the studies involving the general snowboarding population (table 3). While these broad studies encompass any injury that presents to the selected location (ski patrol, hospital), some elite-snowboarding studies will specify acute injuries as those injuries that result in one or more time-loss days, while others will include all injuries requiring medical attention (table 3). As the research community works to produce more literature specific to this elite group, it may be useful to establish a methodology for reporting and recording injury.

It is difficult to compare the injury rates for the elite-level snowboarders with the general snowboard population due to differences in reporting injury incidence. However, the methods for reporting injury rates within the expert group are more consistent (table 3), and may show an increase in due course. Torjussen & Bahr[26 27] reported incidences of 4.0 injuries/1000 runs and 1.3 injuries/1000 runs in 2005 and 2006, respectively, for competitors at the elite-level (*note: rates are reported per 1000 runs and not 1000 skier days*). In 2013, Major *et al*[49] described an increase in these rates as averaged over a 6-year time period, with 6.4 injuries/1000 runs.

Despite the inconsistencies with injury-rate definitions, it is apparent that the severity and location of injuries vary across skill levels.[9 16 24 26 28 29 51–53] When reporting on snowboarders as a whole, relatively minor wrist sprains, fractures,

Table 2 Snowboarding injury patterns from 1996 to 2011: injury sites as percentages of all injuries

Citation (chronological)	Study type	Time frame	Injury setting	Snowboard injuries	Upper extremity	Lower extremity	Head/neck/ face	Trunk	Shoulder	Arm/ elbow	Wrist	Knee	Ankle/ foot
Sutherland *et al*[11]	Retrospective	1995	Ski Patrol Reports*	88	47	24	15	10				15	9
Chow *et al*[13]	Prospective	1993/1994 season	Hospital or Medical Clinic Reports*,†	355	57.9	15.5	17.7						
Davidson Laliotis[14]	Retrospective	1989/1990–1992/ 1993 seasons	Ski Patrol Reports*	929	37	38	11		8	7	19	17	16
Pigozzi *et al*[15]	Retrospective		Injuries Reported for Insurance Coverage*	106	45.1	38.5	1.9	14.1	16	4.7	4.7	16.9	14.1
Sasaki *et al*[2]	Retrospective	1991–1997	Hospital or Medical Clinic Reports*	1445	51.3	27.2	13.4	8.1	16.7	11.1	18.7	8	11.3
Idzikowski *et al*[16]	Prospective	1988–1999	Hospital or Medical Clinic Reports*	7430	49						21.6		
Machold *et al*[17]	Prospective	1996/1997 season	Self Reported+Hospital or Medical Clinic Reports*	152	61	21	11.2	2	5.9	3		7.9	
Langran Selvaraj[3]	Prospective	1999/2000 season	Ski Patrol Reports+Hospital or Medical Clinic Reports‡	213	46	21.6	22.1		8.9		22.1	12.2	
Made Elmqvist[4]	Prospective	1989–1999	Hospital or Medical Clinic Reports§	568	54.4	19.2	14.6	11.8				9.5	4.9
Yamagami *et al*[5]	Retrospective	1992–1999	Hospital or Medical Clinic Reports*	3243	37	19	25	19	12	10	12	6	8
Xiang *et al*[22]	Retrospective	2002	Hospital or Medical Clinic Reports*,†	62 000	38.5	18.5	16.6	11.6	14.7	16.6	17.9	6.4	
Sakamoto Sakuraba[7]	Retrospective	2002–2005	Hospital or Medical Clinic Reports*	2220	49	22	14	15					
Wasden *et al*[41]	Retrospective	2001/2002–2005/ 2006 seasons	Hospital or Medical Clinic Reports*,†	348	11.78	26.15	27.3						
Ishimaru *et al*[28]	Retrospective	2004/2005–2008/ 2009 seasons	Hospital or Medical Clinic Reports*,†	7793		12.3							
Sulheim *et al*[8]	Retrospective	2002	Ski Patrol Reports*	1387	40.6	16.8	19.8		11.4	9.2	25.9	6.8	5.6
Dickson Terwiel[36]	Prospective	2007 season	Hospital or Medical Clinic Reports*,¶	802							17.7		
Average				5567.40	44.7	22.8	16.2	11.5	11.7	8.8	17.7	10.6	9.8

*All injuries.
†All injuries reported to the emergency department specifically of hospital.
‡Non-traumatic episodes excluded.
§All injuries presented to clinic within 48 h.
¶Included physiotherapy practices in addition to hospitals.

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Table 3 Elite snowboarding studies and injury incidence

Citation (chronological)	Study type	Time frame	Injury report	Injury definition	Injury incidence
Torjussen *et al*[26]	Prospective injury registration	2001–2002 season	Registered injuries followed up with self-report	All acute injuries (miss one or more days of competition or training)	4.0 injuries/1000 competition runs
Torjussen *et al*[26]	Retrospective interviews	April 2000–2001	Self-reported*	All acute injuries (miss one or more days of competition or training)	3.4 injuries/1000 competition runs
Torjussen *et al*[27]	Retrospective interviews	April 2002–2003	Self-reported*	All acute (miss one or more days of competition or training) and overuse injuries	1.3 injuries/1000 competition runs 7.0 injuries/1000 competition days
Engebretsen *et al*[48]	Prospective injury registration	2010 winter olympic games	Physician-reported	All injuries that received medical attention	
Florenes *et al*[9]	Retrospective interviews	2006/2007 –2007/2008 seasons	Self-reported*	All injuries that occurred during training or competition and required medical attention	56.3 injuries/100 athletes
Major *et al*[49]	Retrospective interviews	2007–2012 (interviews at the end of each season)	Self-reported*	All acute injuries sustained during training or competition requiring medical attention	40.1 injuries/100 athletes 6.4 injuries/1000 competition runs

*Coaches and team physicians also contributed.

lacerations and contusions are among the most common injuries.[16 21 54] In terms of injury mechanism, those at the beginner level are likely to injure themselves during an isolated fall.[16 29 30] However, when snowboarding injuries are stratified by skill-level, these types of injuries decrease and high-impact injuries associated with attempted expert tricks become more traumatic and more prevalent across all injury locations.[9 16 29 52 53]

Studies specific to those at the elite level consistently report an elevated incidence of high-severity injuries. For instance, a 2013 report found that 72% of World Cup snowboarding injuries resulted in time loss, and that severe injuries were the most common injury type for snowboarders (42%), as opposed to slight, moderate, mild or minimal severity classifications.[49] This increase in the injury severity among the elite-level snowboarders is additionally exemplified by a 2009 survey of World Cup Ski and Snowboard athletes, where severe injuries were again the most common injury classification, and it was estimated that the annual risk of severe injuries among the professional snowboarders is comparable to that of professional American football players, with about a third of World Cup snowboarders experiencing a time-loss injury during the winter season.[9] Furthermore, incidences of high time-loss injuries (such as knee anterior cruciate ligament (ACL) tears) are likely to be underestimated, due to the nature of prospective and retrospective analyses of the elite-level snowboarding injuries. This is supported by two separate retrospective surveys of the elite-level snowboarders, which reported that 50% and 67% of time-loss injuries occurred outside of competition.[26 27]

In addition to injury severity, the location of injuries varies across the skill levels.[24 26 28 51] Table 4 outlines the most common injury sites reported for elite snowboarders: the head/face, shoulder, back, chest, knee and ankle.[9 26 27 49] When comparing the percentages for these injury, locations between the reported percentages for the general snowboard population (table 2) and the elite population (table 4), the head/face, shoulder, trunk and ankle have similar rates, with a slightly decreased incidence in head injuries and slightly increased incidence in shoulder, trunk and ankle injuries. Notably absent from the common injuries in elite boarders is the most common overall injury in recreational snowboarders, injuries to the wrist (table 2). In elite snowboarders, injuries specifically to the wrist represent only 5–6% of all injuries.[9 49] The knee appears to have elevated rates for the elite population compared with the general snowboarding population.

This discrepancy is most likely due to the injury mechanism. Instead of a simple isolated fall, landing from high amplitude jumps is the most common mechanism of injury for the elite-level snowboarders.[26 55] The snowboard cross, a discipline where several snowboarders race down a course which includes several jumps, has recently been identified to have one of the highest risks for injury out of all Winter Olympic events.[48] While some of these injuries are due to collisions with the competitors, there was a high proportion of injuries in training runs, where athletes were alone on the course. Additionally, an analysis of the mechanisms of injuries in the snowboard cross found that 13 of the 19 analysed cases were due to an error while jumping.[55] Other events that involve high-amplitude jumping, such as the 'big air' event and the 'half-pipe', where snowboarders perform a series of aerials, also have high-injury rates.[26 27 48 49] During these types of jumps the lower extremities become more prone to injury because they have to absorb large impact forces. The overall percentage of lower extremity injuries is increased to some extent in the elite-level snowboarders compared with all snowboarders, but knee injuries represent the greatest increase in injury location when elite-level snowboarders are considered independently. The three most recent findings that we identified to include a percentage for knee injury as a function of total injuries in the general snowboarding population reported knee injury rates between 6% and 6.8%.[5 8 22] These percentages increase dramatically for the elite-level snowboarding population, where knee injuries are often the most common injury site and the rates reside at just under 20% of all injuries.[9 26 27 49] In fact, a recent survey of World Cup athletes reported no difference in the number of knee injuries between snowboarders and alpine skiers, who have a notoriously high knee injury incidence.[9]

Overall, snowboarders are more likely to injure their ankle than Alpine skiers.[35 56 57] Ankle injury incidence in elite snowboarders has been reported to be 7–11% of all injuries.[9 27 49] While ankle injuries do not necessarily represent a large disparity between the elite and overall snowboard populations, they

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Table 4 Injury rate percentages for most common injury sites for elite snowboarders

Citation (chronological)	Snowboard injuries	Head/face	Shoulder/clavicle	Back	Chest	Knee	Ankle
Torjussen *et al* [26] *	84	13	10	13	12	16	
Torjussen *et al* [27]	135	7	13	13	6	18	11
Florenes *et al* [9]	574	12.9	13.3	10.3§	2.6¶	18.9	9.4
Major *et al* [49]	233	16†	12†	11†,§	3†,¶	18†	11†
		10‡	14‡	10‡,§	6‡,¶	17.5‡	7‡

*Injuries reported for retrospective interview portion of study.
†Injuries reported for women.
‡Injuries reported for men.
§Lower back, pelvis, sacrum.
¶Sternum, ribs, upper back.

are a substantial portion of injury. Additionally, unique ankle injuries manifest with regard to snowboarding; consequently, the topic is relevant to this discussion. Other lower extremity injuries, such as injuries to the hips, thighs and lower legs, are uncommon, averaging a combined total of less than 10% of all injuries in expert riders.[26 27]

It is important to note the different stances in snowboarding compared with skiing when considering the lower extremity injury. There are two stances: a 'regular' stance where the left leg is the leading leg and a 'goofy' stance where the right leg is in front. In addition, a snowboarder can ride 'switch' where the leading leg is the non-preferred leg. While a difference in injury pattern between riding regular, goofy or switch has not been established,[10] it is reported consistently that the leading leg in snowboarders is injured more often than the trailing leg,[12 21 25 28 47 58 59] a laterality which is not observed in skiing.[60 61] In fact, it has been reported that up to 90% of lower extremity injuries,[25] and 89% of ACL injuries (33 of 37 participants) affect the leading leg.[51] Davidson *et al*[14] reported that the difference in the number of injuries for the leading and trailing legs was present for both knee and ankle injuries, but was only significant for knee injuries. For upper extremity injuries, there was no correlation between the affected side and the leading leg,[14] or whether the rider has a regular or goofy stance,[35] but rather the injured side was related to the direction of falling.[19 35] There is currently no explanation in the literature as to why the leading leg appears to be much more vulnerable compared with the trailing leg.

Common lower extremity injuries

Injuries to the knee

Of the various knee structures, the medial collateral ligament (MCL) and ACL are the most commonly injured.[9 10 62] Kim *et al*[10] reported in 2012 that injuries to the MCL and ACL were in the top 10 injuries among all snowboarders. While we earlier identified that among the snowboarding population, only 13% of snowboarders described themselves as 'advanced', of the snowboarders who injured their ACL in this study, a disproportionate 38.5% considered themselves as 'experts'. Furthermore, 60% of these injuries happened in terrain parks.[10] The Colorado Snowboarding Injury Survey's 8-year results reported 644 knee injuries, with knee ligament afflictions representing 11% of all injuries.[62] Of these, 275 injuries were to the MCL and 144 were to the ACL. However, the beginners were more susceptible to MCL injuries, while 85% of the ACL injuries were to either expert or intermediate riders.[62] In a 2011 analysis of 19 competitive snowboard cross injuries, 6 knee injuries were reported, of which half were ACL injuries and one was an injury to the MCL.[55] Although ACL injuries in snowboarding have been largely overshadowed by the high rates observed in alpine skiing, both ACL and MCL knee injuries do occur, and it seems that ACL tears disproportionately affect the expert riders.

While the exact biomechanical mechanisms of ACL injury in snowboarding have yet to be determined, one proposed mechanism is the 'big air, flat landing' mechanism, where it is theorised that an error in take-off results in jumps that are too high and far, and consequently, conclude in a 'flat' landing.[10 51 55] Flat landings are described as landings that occur outside of the transition, which is the portion of the slope that is inherently protective in that it provides a graded change from a steep inclination to a horizontal surface. Flat landings occur on more horizontal surfaces. A 2009 retrospective interview review of 38 ACL injuries described this mechanism as the cause of 35 of the injuries.[51] When a snowboarder lands 'flat', the ground reaction force is more perpendicular to the board and in line with the legs, which directs more of this force to directly compress the joints and allows for less time to absorb the impact. During this type of landing, there is an increased eccentric contraction of the quadriceps, which in turn causes an increased loading to the ACL,[51 63] and the shorter amount of time for deceleration results in a higher impulse on the leg. An alternative injury mechanism for the 'flat' landing, or any unstable landing, is the valgus-collapse mechanism evident in many non-contact ACL injuries.[57 64 65] When landing 'flat', a knee in valgus may be exposed to a large valgus torque, which has been shown to strain the ACL and lower the threshold for an ACL tear.[63 66] Unlike in skiing, snowboarding equipment does not act as a lever arm for torque about the joints of individual limbs, and it has been speculated that the lower limbs of snowboarders are protected from rotational forces because both feet are attached to the board.[11 12 15 21 26] However, the fixed binding position on the snowboard may increase the possibility of landing in a valgus knee position and/or with the knee in internal rotation due to the inability of the foot and leg to naturally position themselves relative to the snowboard while airborne. Clearly, more research is needed to identify the injury mechanisms.

Injuries to the ankle

Although a 2011 analysis of lower extremity snowboarding injuries reported that the ankle was the most frequently fractured site on the lower extremities,[28] ankle sprains (52%) are more common in snowboarding than ankle fractures (44%).[58] Today, most snowboarders use soft boots as opposed to hard boots[21]; however, overall ankle injury rate does not appear to be significantly affected by the boot type.[21 58]

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Snowboarding ankle fractures are most commonly of the medial or lateral malleoli (64%).[58] Thirty-six per cent of fractures are to the talus, and of these, 95% are specifically to the lateral process.[58] The fracture of the lateral process of the talus (FLPT) is a sports injury largely unique to snowboarding and represents up to 15% of reported snowboarding ankle injuries and 2.3% of all reported snowboarding injuries.[21 58 67] The incidence is elevated among those wearing the less common hard boots.[58] It is frequently misdiagnosed as an anterior talofibular ligament sprain, and was considered rare until the growth of snowboarding.[54 67 68] Snowboarders who injure their ankle are 17 times more likely to fracture the lateral process of the talus than the average person with an ankle injury, and, for this reason, it is often referred to as the 'snowboarder's fracture'.[69] The injury mechanism has been classified as dorsiflexion of the ankle and inversion of the hindfoot,[68–71] combined with axial loading,[72] particularly during the high-impact injuries associated with the experienced riders. Boon *et al*[72] demonstrated that the external rotation was also an important component to this injury. The FLPT is often overlooked, because it is difficult to see on a standard ankle radiograph and many clinicians are unfamiliar with this injury.[21 67] Failure to properly diagnose this relatively obscure injury can lead to chronic disability and potentially the end of participation for an athlete (figure 1).[67]

Biomechanical analysis of injury mechanism and injury prevention

Injury rates for snowboarders of every skill level are high compared with alpine skiing.[2 4 7 10] The mechanisms of head and upper-extremity injury have been investigated and injury prevention strategies, such as wearing helmets and wrist guards, have been implemented and shown to reduce injuries.[6 31–34 36 37] Back protectors are also used to attempt to prevent and/or mitigate the spinal injuries.[73] However, no such protection has been developed or tested for lower extremity injuries, which could disproportionately exclude the expert riders from preventative measures. A 2013 systematic review of injury-prevention recommendations for skiing and snowboarding outlines the current emphasis on the equipment as a protective measure, although they omitted the elite athletes from their analyses.[74]

Most of the articles describing the mechanisms of injury in snowboarding rely on the recollection of the patient.[12 16 28 51] Video analysis has proven useful for the more objective characterisation of injury events in other sports in terms of situational descriptions of the injury incident, mechanism, athlete behaviour and individual-specific variables, but we found only one such article pertaining to snowboarding injury in snowboard cross.[55] More analyses of this nature are needed for snowboarding, especially in the other snowboarding disciplines such as the half-pipe and slopestyle events.

While patient recall and video analyses are important tools for investigating the injury situations and patterns in sports, quantitative kinematic and kinetic measurements provide the scientific metrics for injury mechanisms (figure 2). Obtaining these types of data in snowboarding is technically challenging and, therefore, there are limited reports in the literature.

Several feasibility studies have attempted the kinematic and kinetic analyses of the lower extremities in snowboarding.[75–77] A 2006 study used four high-speed cameras for video data collection and a force plate mounted on the snowboard to record the force during jump landings, and concluded that this method had potential for future biomechanical analyses.[75] Another such study used full-body inertial and insole measurement systems.[76] The inertial suit is an alternative to the traditional motion capture, which has high accuracy but is difficult to carry out in an outdoor environment, especially in the snow. They reported differing kinematics between an inertial suit and their video analysis, and identified other limitations of the inertial suit compared with the motion capture, such as the inability to identify an absolute position of the snowboarder in space. Additionally, the insole measurement system had high deviations.[76] In 2011, the inertial suit was used again in conjunction with the custom made force plates beneath the bindings.[77] While this group stated that their data were reasonable in comparison with other studies, no validation was provided for their methodology.

The mechanisms of injuries specific to the ankle have been better evaluated. Delorme *et al*[56] measured inversion, plantar flexion and internal rotation of the ankle joint with a portable electromagnetic motion tracking system, where the computer unit was in a backpack on the snowboarder. Four sensors were placed on the skin of the snowboarder, and the source was placed on the board between the bindings. This group reported significant kinematic differences about the ankle joint with regard to the leading versus trailing leg and between the hard and soft boots. Boon *et al*[72] examined the mechanism of the fracture of the lateral process of the talus using cadaveric ankles in a materials testing apparatus. The ankles were loaded to failure with different combinations of external rotation and fixed dorsiflexion and inversion, demonstrating that external rotation is a component of the injury. Both groups suggested

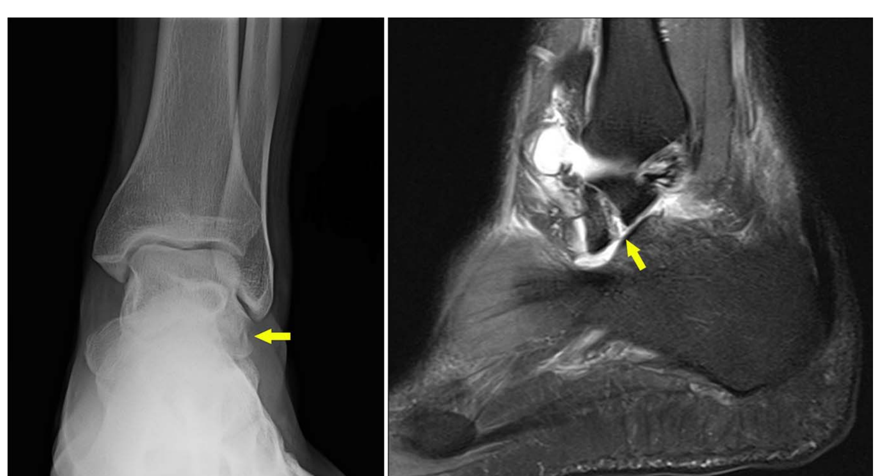

Figure 1 Illustrative example demonstrating a radiograph (left) and MRI (right) of a lateral talus fracture in a snowboarder.

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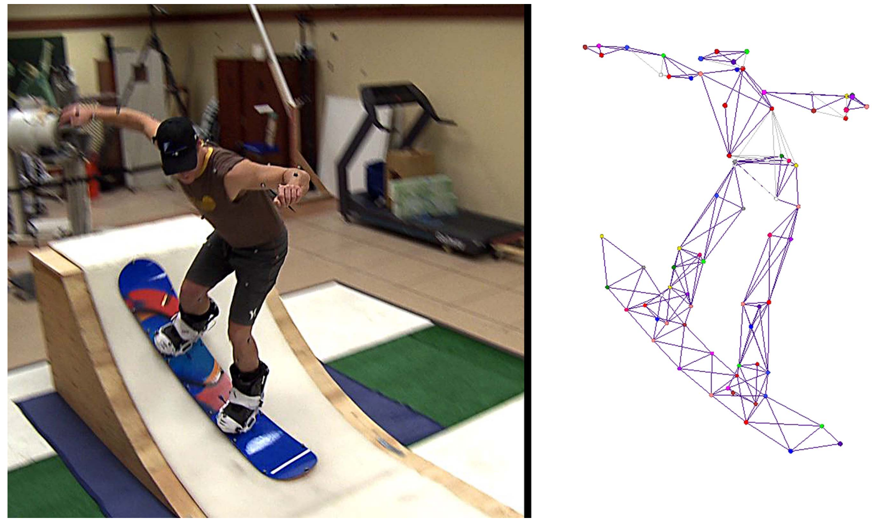

Figure 2 Feasibility study of motion capture analysis of a half-pipe landing.

further studies on the mechanisms of injury to the ankle joint complex.

CONCLUSION

Although there is limited information specific to injuries at the expert level in snowboarding, the existing articles have identified a significantly divergent injury pattern when experts are considered independently. The incidence of severe injury and lower extremity injury is increased and the incidence of upper extremity injury is decreased in the experts compared with beginner snowboarders. Unfortunately, biomechanical analyses of the mechanisms of these injuries are lacking, and consequently, injury prevention strategies are also lacking. For effective prevention measures to be developed, it is imperative to understand the biomechanical injury mechanism of action. Several methodologies for biomechanical analysis of the lower extremities have been tested, but have yet to provide adequate data to identify the in vivo injury mechanisms. In conjunction with biomechanical analyses, additional information about external risk factors such as equipment (bindings), environment (snow conditions) and events (half-pipe, snowboard cross) are needed to better elucidate the injury risk among the snowboarding community.

What are the new findings?

- There remains a paucity of information specific to injuries at the elite-level in snowboarding.
- Incidence of severe injury and injuries to the lower extremity increased and upper-extremity decreased for the elite-level snowboarders.
- Scientific information with regard to biomechanical analyses and injury prevention for the lower extremities in snowboarding are needed.
- Scientific information with regard to external risk factors of injury are needed.

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