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Injury rate and injury patterns in FIS World Cup Alpine Skiing: Have the new ski regulations made an impact?

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Table of contents

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Abbreviations

FIS	International Ski Federation
FIS ISS	FIS Injury Surveillance System
OSTRC	Oslo Sports Trauma Research Centre
WC	World Cup
WSC	World Ski Championships
OWG	Olympic Winter Games
DH	Downhill
SG	Super G
GS	Giant Slalom
SL	Slalom
ACL	Anterior Cruciate Ligament
RR	Risk Ratio
CI	Confidence interval

1. Introduction

1.1 Background

The FIS Alpine Ski World Cup (FIS WC) is considered by many to be the fastest and most exciting event series in international sports. Alpine skiing has been on the Olympic program since 1936. The first WC ski race was held in 1967, and today the WC alpine skiing events include downhill (DH), super – G (SG), giant slalom (GS), slalom (SL) and super combined. Super combined is a combination of a SL event with a SG or DH race (1). Racing is performed at speeds that can approach 160 km/h (DH) or takes place on extremely steep terrain (SL). Therefore, the FIS WC is very demanding with immense physical requirements for the elite skiers to keep the whole body in a streamlined and aerodynamic position (DH and SG) or make tight turns in rapid succession (GS and SL) (2). The FIS WC in 2013/14 included 69 races for both sexes from October to March in 28 locations across 12 different countries (3). The WC events attract high numbers of viewers and audiences across Europe and North America, with a great deal of sponsors.

In the 1990's came the introduction of the carved aluminium skis. The worldwide ski community experienced a great turnover from traditional skis to carving skis. The development of the skis went through considerable changes in length and sidecut of the ski. The popularity of these skis grew enormously. A study from 2008 reported that when comparing winter seasons, the use of carving skis increased from 4% to 61% among the skiers included within 4 years (4). This development of the carving skis also meant substantial changes for the competition equipment in alpine ski racing.

1.2 Injury risks and injury patterns

Alpine ski racing is considered as a high-risk sport and is not unknown to include crashes and injuries. Studies have earlier reported injury risks and specific injury patterns in WC alpine skiing (5-8). The majority of these studies are based on data from the FIS Injury Surveillance System (FIS ISS), established by FIS prior to the 2006/07 season. The objective of the FIS ISS was to provide data on the injury rate and patterns in international skiing and snowboarding. Bere et al. (2013) reported that one third of WC alpine ski racers sustained an injury during a season, and the most common injury location, expressed as injured body part, was the knee (38%) (7). Furthermore, a study reported the perceived risk factors in alpine skiing after interviews with experts. They found five main risk categories, among them: system ski, binding, plate and boot; changing snow conditions; physical aspects of the athletes; speed and course setting aspects and speed in general (6). The ski equipment was perceived as a risk factor in WC alpine ski racing and with the development of the carving ski over the years; experts were concerned about the increased aggressiveness of the skis. Too aggressive ski equipment could lead to out of balance situations and severe injuries (9). As previous studies had investigated and described the injury mechanisms of and the events leading to severe knee injuries, there were concerns about the aggressive ski snow interaction (9, 10). After testing and evaluation of different ski prototypes with a decreased self-steering behaviour and more controllability, FIS introduced new regulations of the ski equipment prior to the 2012/13 season, in effort to increase the athletes' safety (11).

1.3 Context and aims of the thesis

The American technical alpine racer, Resi Stiegler (29) has experienced several injuries and multiple surgeries during her career, among them two ruptures of the ACL. During the FIS World Ski Championships (WSC) in Beaver Creek in 2015, the skier replied during an interview, after having to withdraw from the second run of the slalom because of a knee injury she suffered from a month before the competition.

"Just having (the injuries) happen again and again is pretty difficult. Coming back isn't the difficult part. I know I can do it. It's wanting it so badly that's difficult," (12)

To our knowledge no previous study has examined and compared the injury incidence before and after the new regulations of ski equipment in WC alpine skiing. We do not know if the implementation of new ski equipment influences the injury incidence and injury patterns. As the example with Resi Stiegler, WC alpine ski racers may suffer several severe injuries during their professional career. Whether new ski regulations reduce the risk of injuries among alpine ski racers needs to be investigated.

The purpose of this study was to investigate the injury incidence and injury patterns in six seasons (2006-12) before versus two seasons (2012-14) after the new regulations for ski equipment in FIS WC, including the WSC and the Olympic Winter Games (OWG). Our null hypothesis was that there would be no difference in injury incidence between the seasons before and after the new regulations.

2. FIS World Cup Alpine Ski Racing

2.1 Race structure, disciplines and courses

The following section will describe some of the rules, specifications and technical data of the four main disciplines in the FIS WC and the sport in general. Most of the content describing the four different disciplines are collected from different paragraphs in the International ski competition rules (ICR) (13).

Picture 1: *Part of the downhill/super-G slope at the WC finals in Meribêl, France 2015. Photo: Author*

Downhill (DH)

The modern discipline of downhill employs a course designed to exploit terrain features to optimize speed, provide challenges, and protect the competitor. Downhill is referred to as a speed event. The event is considered to be the most difficult and quickest of the alpine events with skiers reaching speeds well in excess of 100km/hr. This takes tremendous skill, strength and concentration (14). Of all the disciplines, downhill courses cover the longest distance, over the greatest drop in elevation (males 800m-1100m and females 450m-800m) and with the longest distance from one gate to another. Compared to the other disciplines the gates in downhill only serve to delineate the racing line. The downhill race is a one run race, meaning that the competitor race the course only once, and the fastest time wins. Downhill racers are required to participate in one training run before the race (13).

Slalom (SL)

The second discipline that was developed was slalom. SL was the first well defined race discipline, so some historians regard it as the first codified race discipline (15). The modern discipline of SL employs a course set designed to exploit terrain features in a manner that demands great technical skills to turn, control speed, and optimize line. SL courses cover the shortest distance, at the lowest speed, over the smallest drop in elevation (male 180-220m and female 140-220m), with the least distance from one gate to another. The distance from turning pole to turning pole of successive gates must not be less than 6m and not more than 13m (13). The number of gates is between 42 and 77 and skiers usually take between 40-60sec to complete a slalom course (14). SL is referred to as a technical event because it emphasizes subtle technical skills required to turn, negotiate line, and manage speed. The SL race is a two run race. Only the 30 best skiers qualify for the second run. The times for both runs are added together to yield a total time. The fastest total time determines a racer's order of finish, or result. There are mandatory course elements for slalom racing. Specifically there must be a minimum of three hairpin combinations and from one to three vertical gate combination(s) consisting of three to four gates (13).

Giant Slalom (GS)

Giant slalom, was the third discipline to be introduced, after DH and SL, and is classified as a technical event. It is set over longer courses than SL, but shorter than SG. The distance between two successive gates must not be less than 10 m and the number of gates must be between 28 and 68. GS has a minimum drop in elevation of 300m for both sexes and ranges up to 450m for males and 400m for females (13). It emphasizes fast technical turns that are rounder and longer than those found in SL. GS rewards precision, control, and balance. GS is also referred to as a technical event because it emphasizes technical skills required to turn and negotiate line, and additionally manage speed (15). It is shown that the small turn radii provokes the skiers to use their full backward and inward leaning capacities (5). The GS is a two run race where the 30 best skiers from the first run qualify for the second run. The times for both runs are added together to yield a total time. The fastest total time determines a racer's order of finish (13, 15).

Super G (SG)

The SG is the most recently introduced discipline. SG is also a speed event. It is set like downhill courses but over shorter distances and with a drop in elevation ranging from 400-600m for females and up to 650m for males. The number of gates is normally set to between 28-45 gates and the distance between the gates must be at least 25m. With more turning, and limiting the straight gliding found in downhill, it is still a fast event. SG skiers must turn technically good and also maintain an aerodynamic position when possible (16). SG is a one run race and it has no training run. It was developed in the early 1980’s in response to a desire that the overall WC winner would be a versatile skier that exhibits cross-discipline skills. At that time, the top levels of ski racing had evolved into technical event specialists and speed event specialists. It was intended that SG would be a speed event that technical event racers could be comfortable with (15).

2.2 Physical characteristics of alpine skiers

Alpine ski racing demands aerobic and anaerobic power, muscular strength and a set of various complex motoric skills, such as coordination, balance, agility and adeptness (16). The physical characteristics vary between disciplines. Ski racers competing in the technical events have been found to weigh less on average than the racers in speed events (16). In general, alpine ski racers have very high leg strength compared with other athletes (17).

Indirectly, aerobic power is important for alpine skiers, especially to endure all the physical training during the preparation for a new season. Anaerobic power is also essential in alpine ski racing and is of high priority during training. Alpine skiers must be able to ski with heavy load at the end of a run, with a noticeable deal of discomfort without influencing the performance (18). A great deal of forces influence the alpine skiers during turning, such as air drag, gravitational and snow reaction forces (19).Thus, muscular strength is of importance, not just during one turn but during multiple turns (18). Alpine ski racing also demands a variety of general coordinative skills and a set of specific motoric skills. The specific set of skills is in practice exercises that imitate the specific sport. In order to practice these imitations, a high level of dynamics (rhythm, flow) and stability is required of an alpine skier (18).

2.3 Equipment

Racing skis

In contrast to recreational skiing, specific rules for equipment are determined by FIS to make competitive skiing safe and fair (Table 1) (20). The definition of alpine racing skis is that they are `skis, predominantly for use in downhill, slalom, giant slalom and super-G, racing on suitable terrain and utilizing the force of gravity. In order to allow transmission of lateral forces, the edges of the running surface of the ski are made mainly of a hard material resistant to wear and tear` (FIS, page 2.) (20).

Table 1: A description of the minimum required length and radius of the alpine racing skis for the specific disciplines for the recent seasons (2012-14).

	2011/2012		2012/2013		2013/2014	
	Ski length (minimum)	Ski radius (minimum)	Ski length (minimum)	Ski radius (minimum)	Ski length (minimum)	Ski radius (minimum)
DH male	215	45	218	50	218	50
DH female	210	45	210	50	210	50
SG male	205	33	210	45	210	45
SG female	200	33	205	40	205	40
GS male	185	27	195	35	195	35
GS female	180	23	185	30	185	30
SL male	165	-	165	-	165	-
SL female	155	-	155	-	155	-

DH –downhill, SG- super-G, GS-giant slalom, SL-slalom. Length/radius presented as millimeters.

The alpine racing skis have been subject to a major development since the 1980s (21, 22). Masia (2005) described the evolution of the ski shape, especially the sidecut – as `the subtle hourglass shape of the ski` (21). This hourglass shape or sidecut is easily seen when viewing from above (Figure 1). In almost all cases the curve is circular. The important effect of sidecut is that when the ski is put on edge on the snow the curve will try to lead the ski around a circular path. Lemaster (2010) described that when the ski is put on edge at low to moderate angle to the snow, its steering angle will vary along the ski's entire length. There is greatest steering at the front of the ski and because the tip always has a greater steering angle than the rest of the ski, the ski will turn as it moves forward. The sidecut will make the ski turn itself (23).

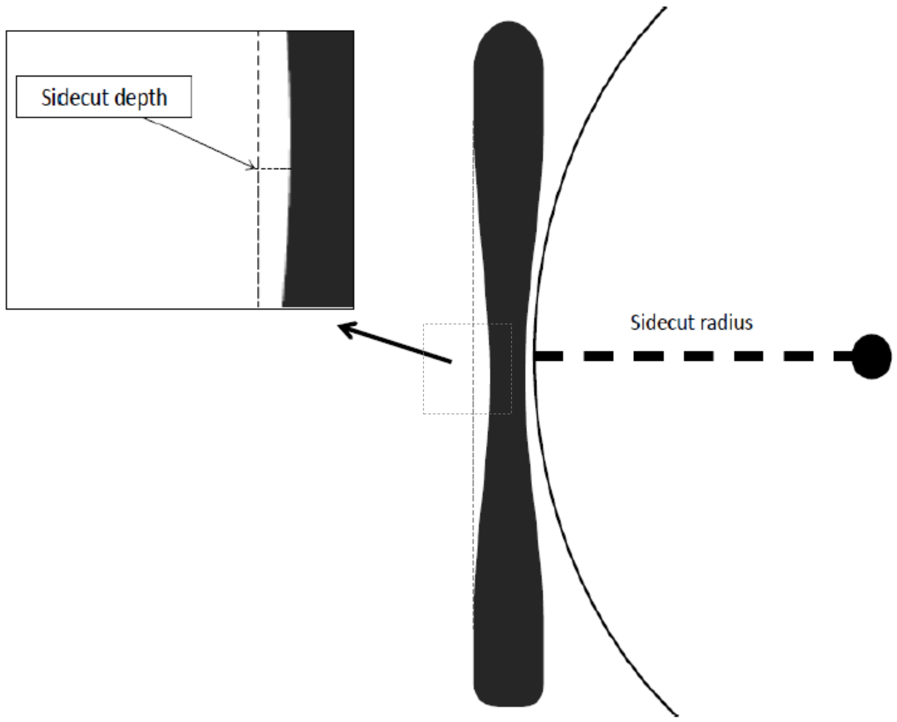

Figure 1: *Sidecut radius and depth of an alpine racing ski. Illustration: Author.*

The background for the study that led to the most recent change in regulations for equipment was based on previous reports from FIS ISS (2006-11), an explorative qualitative study with an aim to identify key injury risk factors and systematic video analysis of ACL-injury mechanisms (6, 10, 24). Based on the FIS ISS reports, it was reported that of all the injuries in the different disciplines during five seasons (2006-11), one third of the injuries in DH and GS were severe (>28 days absence) and knee and ligamentous injuries were the most common injuries (24). The explorative qualitative study by Spörri et al. (2012) aimed to explore the perceived intrinsic and extrinsic risk factors for overall severe injuries in WC alpine ski racing. Based on interviews of 61 experts (athletes, coaches, officials and equipment companies), five main risk factors were identified (6). Of these five risk factors, focus was directed towards course setting/speed, snow conditions and equipment (combination of ski, binding, plate and boot) (25).

Based on the aforementioned, two monitoring projects and one ski prototype evaluation project was started. These projects had an aim to provide deeper understanding of the risk factors and to evaluate approaches for prevention and enhanced safety (26).

One of the projects investigated course setting's impact on speed, energy and forces affecting the athlete, using forerunners equipped with sensors and GPS devices (5). The second project measured snow conditions along the race courses to assess the impact on speed and various forces impacting the racers (25). The ski prototype evaluation project was a collaboration between the University of Salzburg (UNI SBG) (Austria), FIS and the Ski Racing Suppliers association (SRS). FIS and SRS agreed that the goal of the equipment review process was `to only implement new regulations that are scientifically proven to increase safety for the athletes and reduce risk of injury` (11). Based on expert interviews (6), constructional and financial factors (SRS), possibilities of changes in regulations (FIS) and their knowledge and experience from past history (25, 26), they defined the specifications for the prototypes. Ski boots and binding release mechanisms were considered driving factors for equipment safety, but due to limitations and regulation problems, they were not evaluated by the project (26). By the use of top level athletes they tested prototype skis for DH and GS. The choice of testing prototype skis in these disciplines was most likely based on reports of higher number of severe injuries in DH and GS compared to SG and SL (24). One other driving factor might also be because studies have found that high kinetic energy from high skiing speeds, like in DH, could lead to severe injuries if a quick energy conversion should occur during an injury situation (6). Furthermore, a study with the purpose of investigating effects of speed reduction in GS by increased horizontal gate distance, found an increased risk of out of balance situations, bringing the athlete into more backwards and inwards positions (27). In the interview study, experts stated that `longer skis are safer and that you feel more comfortable at high speeds`, `less sidecut mean less force and violence in injury situations` and that the equipment was not controllable if the athlete lost his/her balance due to unpredictable self-dynamic behaviour (6). The factors considered by the prototype project was the radius, length, standing height and ski plates (25). The aims for the prototype skis were to increase the safety by a reduction in aggressiveness in ski-snow interaction, decrease the self-steering behaviour of the ski and reduction of the mechanical energy (turn speed) and load (turn forces).

The collaboration between FIS, SRS and UNI SBG and this prototype project led to the new regulations of ski equipment we find today (Table 1). The regulations that made the largest impact were for the GS skis. FIS wanted to change the radius from 27m to 40m for males and from 23 to 35m for females. But after the athletes, coaches and equipment suppliers voiced their concerns, FIS reduced their initial sidecut to the new minimum GS ski sidecut to 35 m and 30 m for males and females respectively (11, 20, 28). With the change in length and sidecut radius, the turning forces were reduced and aggressiveness of the skis was decreased.

Historically, the sidecut of race ski has been subject to change since the 1980s. For the GS race skis, the change of sidecut and a reduction of the waist were easy. In the 80s, some factories put their racers on new skis with a sidecut radius around 32m as compared to the regular ski sold to the public with a radius of 48m. In 1990 an aluminum GS ski with 10mm side cut became reality. Skiers learned to start the turn with a touch more edge tilt getting less tail slip and more speed through the entire arc. The year after came a ski with a side cut radius of just 15m – about 35 percent of the ski used to win a race in 1984. Racers on these skis took eight of the top ten places. At this time the people around the WC paid attention to what was happening. The next development was making the skis shorter. Designers felt the ski was heavy and there was too much mass at the end of the lever. When average width rose (from 72mm to 83mm), the length of the ski fell (from 204cm to 178cm). Additional mass at the tip and tail, combined with improved edge contact through the turn, meant that the new shorter skis could be as stable as the old straight longer skis.

When reaching the 2000s shapes had grown so radical that FIS had to impose limits to the racing skis. It started with limiting the GS skis to a radius of at least 21m. The slalom ski needed to be at least 155cm long for males and 150cm for females (21). From there the sidecut radius for GS skis were further changed by FIS from 21m to 27m and finally, as mentioned, to today's specification of 35m (20).

Bindings and ski stoppers

Safety bindings function as strain limiters. That is, these devices transfer specific demands occurring during skiing to an acceptable limit, and when this limit is overstepped, they release their firm hold on the ski. The maximum standing height (ski, plates and binding) for all categories is regulated to 50 mm. This refers to the distance between the bottom of the running surface of the ski and the ski boot sole.(20). The limitation is set because it is suggested that together with a strong sidecut radius of the ski, high standing height favors a sudden catch of the edge while skiing, which is an important factor leading up to the injury mechanisms specific for WC alpine skiing (6).

The ski stopper is a braking apparatus for skis, the function of which following the release of the safety binding is to stop or bring to a standstill the loose ski within the immediate vicinity of the skier's fall. The use of skis without ski stoppers during competitions or official training runs is prohibited. The functioning of the release mechanism must not be compromised by the method of its mounting. It is the manufacturers' responsibility to ensure that the ski stopper functions correctly (20).

3. Concepts in epidemiological sports literature

Epidemiology is the study of the distribution and determinants of disease frequency (29). The basic tool of epidemiology is the calculation of rates of occurrence of cases of interest in a given population (30). In sports medicine, the incidence rate is predominantly used to study athletic injuries, since one can assume that athletes are without injury at the beginning of their season and it is the incidence of new injuries during their season that is of interest (30).

Incidence is the most basic expression of risk. Risk can be explained as the `likelihood that athletes who are without an injury, but exposed to certain risk factors, will acquire the injury` (31) . These risk factors that can contribute to an event are referred to as external and internal factors. External factors have an impact on the athlete while they are skiing, turning, competing or training. They include weather, snow conditions, rules, discipline etc. Internal risk factors are factors that are a part of the athletes themselves, including biomechanics, fatigue conditioning, technical skills and somatotype (32).

Literature concerning injury incidence in WC alpine racing describes injuries occurring to WC alpine athletes during a run, competition, training, or during one or several WC seasons. For comparisons, exposure data is needed to calculate injury rates. In sports injury research, exposure is often calculated as minutes, hours, days or competitions where the athlete actually runs the risk of being injured (33). In football, exposure has been presented as minutes or hour participating in matches or training (34). There have been different methods of reporting exposure in winter sports. In studies on recreational skiing, the injury incidence was typically reported as injuries per 1000 lift ticket sold, lift runs and per 1000 skier days (35-37).

In competitive ski racing, freestyle, snowboard and telemark, injury incidence has been recorded per 100 athletes or per 1000 runs per season (7, 38-41). With these varying methods, comparisons of injury incidence has been difficult between studies.

Flørenes et al. (2011) proposed that the injury incidence among WC ski and snowboard athletes should be recorded per 1000 competition runs. This method provided the number of injuries that occurred during WC competitions by counting the number of runs for each ski racer (42). This allows comparisons of incidence between similar studies, provided the methods are consistent.

Studies investigating injury incidence often present their findings as Risk Ratio (RR). As an example of RR Bere et al. (2013) presented:

`Men had a higher overall rate of injury (RR 1.24, 95% CI 1,05 to 1.47) than women in training and competitions, expressed as injuries/100 athletes/season.`(7).

For studies investigating injury incidence in alpine skiing, RR is a measure of the association of for example the number of runs to the occurrence of injuries. A RR of 1.0 represents no difference, values <1.0 indicate a reduced risk and values >1.0 indicate an increased risk (43). This means, from the example, that the RR of obtaining an injury among males is higher than among females because the RR is >1.0 (RR 1.24). The example also presents the Confidence Interval (CI). A CI indicates the amount of random error in the estimate and is often set to an arbitrarily level of confidence. If the level of confidence is set at 95%, the CI would include the correct value of the measure 95% of the time (43). A narrow CI indicates little imprecision (uncertainty) and hence a high degree of confidence (44). As CI is presented as the measure of the precision or uncertainty of a population value, the *p* value is presented as a measure of the strength of evidence against a null hypothesis of no difference (44). A significant *p* value of $p<0.05$ corresponds to a 95% CI that does not include the value that indicates equality (44). Equality or no difference in our study is RR = 1.0. This means, if the 95% CI excludes the RR 1.0 in the study, the results are significant at the level of $p < 0.05$. In the example given by Bere et al. (2013), although the *p* value was not presented, the RR for males compared to females was significant because the RR excluded the value 1.0.

4. Injury rate and injury patterns in WC alpine skiing

An initiative was taken by FIS to establish an injury surveillance system (the FIS ISS) prior to the 2006/07 winter season. The objective of the FIS ISS was to provide data on injury trends in international skiing and snowboarding at the elite level with the long - term goal of reducing injury risk (42). To be able to monitor injury risk and injury pattern over time it was important to establish a continuous recording system for elite skiing and snowboarding. A methodological study with World Cup ski and snowboard athletes comparing prospective injury reporting by team medical personnel, prospective injury reporting by the International Ski Federation (FIS) technical delegates and retrospective athlete/coach interviews, showed that retrospective interviews were the most accurate in this setting (45).

Studies have reported that one in every three skier sustained a time loss injury during a WC season (7, 42). Bere et al. (2013) reported 12.9 severe injures (> 28 days absence) per 100 athletes (7). The same study reported that males had a higher overall rate of injury (RR 1.24, 95% CI 1.05 to 1.47) as well as a higher rate of time loss injury (RR 1.23, 95% CI 1.03 to 1.48) than females in training and competitions, expressed as injuries/100 athletes/season (7). A study among young competitive skiers in Sweden reported 1.7 injuries per 1000 hours/skiing (46). A previous study found in athletes competing in the OWG in Lillehammer in 1994 an injury rate of 1.9 injuries per 1000 runs (47). A brief summary of epidemiological studies on injury rate in competitive skiing is presented in Table 2.

It has been reported that the majority of injuries during six seasons in the WC were time loss injuries (82.3%) and almost half of the overall injuries (45.5%) occurred in races. Of the time loss injuries, 43% were severe (>28 days absence) and 31% moderate (8-28 days) (7). Of the injuries reported through several studies, the most common injury location, expressed as body part, was the knee (7, 8, 46, 48). The second and third most common injured body part was the hand/finger/thumb and head (7). The most common injury types in competitive skiing are reported to be joint and ligamentous injuries, followed by fractures/bone stress and muscle/tendons injuries (8, 46).

Table 2: Epidemiological studies on injury rate in competitive alpine skiing.

Authors (Publication year)	Study design	Population	Injury definition	Injury rate
Ekeland et al. (1996)(47)	Prospective survey	OWG athletes (n=555) in Lillehammer ‘94	Injuries occurring during competitions or official training runs	1.9 injuries per 1000 runs
Stevenson et al. (1997) (49)	Retrospective survey	Competitive skiers(n=404) in Vermont, USA	Knee injuries occurring on snow while skiing	27% of respondents reported a knee injury. 22% of females reported an ACL injury (female – male ratio 3.1)
Pujol et al. (2007) (50)	Descriptive epidemiology study.	French elite skiers (n=379)	Ruptured ACL	8.5 ACL injuries per 100 skier-seasons
Flørenes et al. (2009) (8)	Prospective cohort study	WC alpine ski racers (n=521)	Injury with attention from medical personnel during competition or training	36.7 injuries per 100 athlete per season and 9.8 injuries per 1000 runs.
Westin et al. (2012) (46)	Prospective cohort study	Young elite alpine skiers (n=431) in Sweden attending High school.	Time loss injury during competition or training	1.7 injuries per 1000 ski hours and 3.11 injuries per 100 months at High school.
Bere et al. (2013) (7)	Prospective cohort study	WC alpine ski racers (n=1593)	Injury with attention from medical personnel during competition or training	36.2 injuries per 100 athlete per season and 9.3 injuries per 1000 runs.
Hildebrandt & Raschner (2013) (51)	Prospective cohort study	Young elite alpine skiers (n=104) in Austria attending ski boarding school	Injuries requiring interruption or restriction of training or medical attention	235 injuries (88 female, 147 male) among 89 skiers
Stenroos et al. (2014) (48)	Retrospective survey	Competitive ski racers(n=661) of all ages in Finland	Acute injury with a time loss for minimum a week from training	61 injuries (36 male, 25 female) among 661 athletes.

5. Injury prevention

To prevent injuries among skiers, knowledge about why and how injuries occur is needed.(33). Van Mechelen et al. (1992) proposed a four step injury prevention model (Figure 3). Firstly, the extent of the injury problems in alpine skiing must be identified and described. Secondly, the risk factors and injury mechanisms which play a part in the occurrence of alpine ski injuries need to be investigated and described. The third step is to introduce measures or strategies that are likely to prevent or reduce the risk of injuries. This measure should be based on the etiological factors and the mechanism as identified in the second step. In the fourth step, the effect of the measures or strategies must be evaluated by repeating the first step. In addition, a six-stage model has been presented which incorporates the implementation of effective strategies into real life (52). This six-stage model builds on that future advances in injury prevention will only be achieved if research efforts are directed towards understanding the implementation context for injury prevention (52).
So far, the extent of the injury problem in alpine skiing has been described and the injury incidence of the individual alpine disciplines has been investigated (7, 8). Furthermore, studies have described the injury situations and injury mechanisms in alpine skiing (10, 53). Recently, new measures have been introduced, in form of new regulations in equipment (20).The new regulations was introduced in an effort to reduce the risk and severity of injuries in alpine skiing (25). So far, no study has investigated the effect of the implementation of the new regulations of equipment.

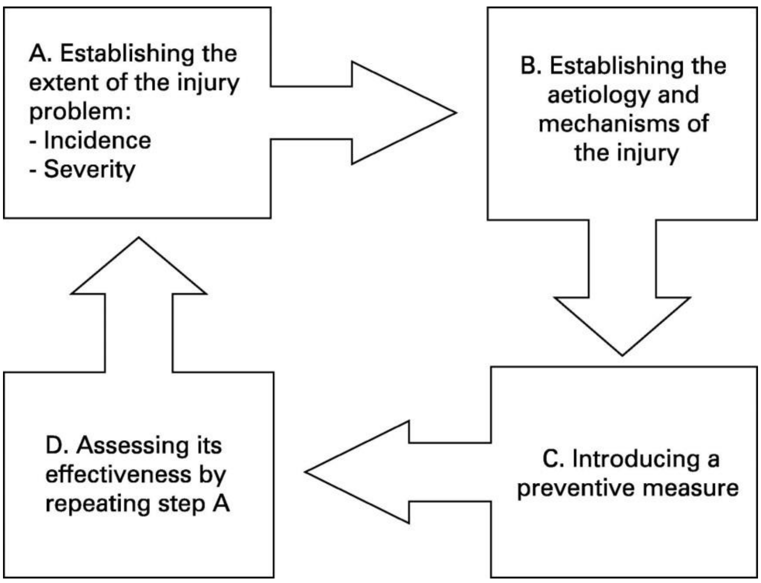

Figure 2: *The four-step "sequence of prevention" described by van Mechelen (32)*

6. Causes of injury

6.1 Risk Factors

An important step in the four step injury prevention process previously described is to establish the causes of injuries. The risk factors and injury mechanisms that play a role in the occurrence of alpine injuries must be identified (54). These risk factors are termed internal or external risk factors (32). Internal factors such age, sex, technical and tactical skills, previous injuries and risk taking behavior may influence the risk of sustaining injuries. In addition, external factors like skis, equipment, snow conditions and course setting may modify the risk of injury, making the skier more vulnerable to injury (54). An injury is the result of an inciting event led by a complex interaction between internal and external risk factors (54).

An explorative qualitative study was undertaken to compile and explore intrinsic and extrinsic risk factors for severe injuries in WC alpine skiing (6). They found, after interviewing 61 expert stakeholders, a total of 32 perceived risk factor categories. The five top categories were: System ski, binding, plate and boot; changing snow conditions; physical aspects of the athletes; speed and course setting and speed in general (6). Another study by Raschner et al. (2012) reported that decreased core strength was predictive of increased ACL injury risk among young competitive ski racers.

6.2 Injury mechanisms

A precise description of the injury mechanism is essential to understand the multifactorial cause of injury (32). The presence of internal and external risk factors is not enough to cause an injury. It is necessary with an inciting event to cause an injury. The key component to understanding the causes of injuries in alpine skiing is the precise description of an injury mechanism (54). The injury mechanism is used to describe vital aspects of the sport situation, a description of the athlete's action and interaction with the opponent or surroundings, a description of the whole body biomechanics and detailed biomechanical characteristics, that is a description of joint/tissue biomechanics (54). Also important, is to identify mechanisms of no injury situations in order to understand which of the apparent mechanisms is actually responsible for the injury (32).

6.3 Injury mechanisms in WC Alpine skiing

Bere et al. (2013) described injury situations in WC ski racing based on systematic video analyses. The main findings were that most of the injuries to the head and upper body resulted from crashes, while the majority of knee injuries occurred while still skiing and while turning. Gate contact contributed directly or indirectly to 30% of all injuries, while only 9% occurred at contact with safety nets/material. Almost half of the injuries (46%) occurred in the final section of the course (53). Another study was undertaken to describe the mechanisms of ACL injuries in WC alpine skiing. The authors identified three main categories of injury mechanisms: The `slip catch`, `landing back weighted` and the `dynamic snow plough`. The `slip catch` mechanism was described by that the skier lost pressure on the outer ski, and while extending the outer knee to reestablish contact, the inside edge of the outer ski caught the snow abruptly, forcing the knee into internal rotation and valgus loading. The same loading pattern was found in the `dynamic snowplough`. The third category of injury mechanisms, `the landing back weighted` included cases where the skier was out of balance backward after jumping and landed on the ski tails on extended knees. The loading mechanism was suggested to be a combination of boot-induced anterior drawer, knee joint compression and quadriceps anterior drawer (10).

Gilgien et al. (2014) found that the skiers are turning for approximately 55% of the time in downhill, 80% in super-G and 93% in giant slalom. Moreover, it was shown that small turn radii might be related to an increased injury risk in giant slalom since they provoke the skiers to use their full backward and inward leaning capacities (5). Out of balance situations are known to be a critical part of typical injury mechanisms, such as the mentioned `slip-catch`, `landing back weighted` and `dynamic snowplough` (10).
In an attempt to so see whether course setting was of importance, Spörri et.al. (2012) investigated the effects of increased horizontal gate distance on energy related and injury mechanism-related variables. They found that longer turns meant that high loading forces where acting over a longer duration, which might increase the athlete’s fatigue. Since high external loads and fatigue have negative impact on balance control, it may increase the risk of an out of balance situation or a fall to occur (27).

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Article: Injury rate and injury patterns in FIS World Cup alpine skiing: Have the new ski regulations made an impact?

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Abstract

Background: New regulations for ski equipment were implemented prior to the 2012/2013 season in the International Ski Federation (FIS) alpine World Cup (WC). **Objective:** This is the first study to investigate the effect of the new ski regulations on the rate, pattern and mechanisms of injury by comparing data before (2006-12) and after (2012-14) the implementation. **Methods:** Injuries were recorded by the FIS Injury Surveillance System (FIS ISS) through retrospective interviews at the end of eight WC seasons (2006-14). All acute injuries occurring in the competitive season that required medical attention were registered. Injury incidence was expressed as the absolute injury rate (injuries/100 athletes/season) and as the relative injury rate (injuries/1000 runs). Exposure was calculated by using official results listed on the FIS webpage. Videos of nine ACL injuries reported through the FIS ISS were systematically analysed in order to describe the injury mechanisms. **Results:** There was a higher rate of injury in training and competitions before risk ratio (RR) 1.47 (95% CI 1.22 to 1.77) compared to after the new ski regulations, expressed as injuries/100 athletes/season. The relative injury rate (per 1000 runs) during WC races was also found to be higher in the seasons before RR 1.60 (95% CI 1.20 to 2.15) the new regulations. No difference was found in the rate of knee/ACL injuries or in the injury mechanisms. **Conclusion:** There was 1.5 times higher risk of injuries in the seasons before the new regulations of ski equipment. The changes done to the equipment therefore seems to be successful.

Keywords: Alpine skiing, FIS World Cup, Alpine skiing injuries, Ski equipment, FIS Injury Surveillance System, Injury Incidence, Epidemiology, Anterior cruciate ligament (ACL), Knee injuries, Video analysis.

Introduction

The International Ski Federation (FIS) Alpine Ski World Cup (WC) is the top international circuit of alpine skiing competitions (1). Alpine ski racing is as a sport with high speed, spectacular jumps and intense turns. One third of the WC ski racers, experience an acute injury during the 5-month winter season (2, 3), and it is suggested that the injury risk is linked with increased skiing speed and turning forces (4). The knee is the most common body part injured with ACL injuries as the most frequent specific diagnosis (2, 3). Distinct ACL injury mechanisms have been identified; the `slip catch`, `dynamic snowplough` and the `landing back weighted`. The `slip catch` and the `dynamic snowplough` are characterised by a common pattern where the skier is out of balance backward and/or inward, trying to regain grip with his/her ski on the snow surface, when the inside edge of the ski abruptly catches the snow, forcing the knee into internal rotation and valgus (5).

For injury prevention, understanding the injury mechanisms and the situations leading to injury is essential (6). Both intrinsic factors and extrinsic factors, such as course setting and equipment, should be considered (6, 7). The alpine ski racing equipment varies between the different disciplines. Over the past years, the skis have been through significant changes in terms of length, width and sidecut radius (the hourglass shaped look) (8). In the speed disciplines, downhill (DH) and super-G (SG), long and straight skis are favourable, giving more stability at high speed (9). While in the technical disciplines, giant slalom (GS) and slalom (SL) with lower skiing speed, but higher turning radius, the skiers want to carve tight turns without lateral skidding (10).Thus, the ski waist, on-edge angle and ski flexion are critical factors (11). The GS skis have been through the most significant changes during the past years. The reason for the most recent change in regulations for the alpine racing skis, was an attempt by FIS to lower the risk of injuries by reducing the aggressiveness of the ski-snow interaction and a reduction in turning speed and forces (12, 13). The sidecut radius and minimum ski length was set to a higher minimum requirement in all skis except SL skis. The new regulations for ski equipment made the skis longer, straighter and less aggressive. The latest change concerning the GS skis was prior to the 2012/13 season, were the sidecut radius changed from 27/23m to 35/30m for males and females, respectively (14).

The aim of this study was to investigate the effect of the new ski regulations on the rate, pattern and mechanisms of injury by comparing data before (2006-12) and after (2012-14) the implementation.

Materials and Methods

Study design and study population

The injuries were recorded in the FIS Injury Surveillance System (FIS ISS) (2, 3, 15) through retrospective interviews at the end of eight WC seasons (2006-2014). Data from the two recent seasons with the new ski regulations (2012-2014) was compared with data from the previous seasons (2006-2012). The WC seasons were defined as starting at the first events in Sölden (Austria), in October, lasting until the WC finals in March. Athletes, identified from the official FIS website, had to have started in at least one WC or World Ski Championship (WSC) event throughout the season to be included in this study. Athletes who were defined by the coaches as European Cup (EC) athletes, and therefore not a part of the WC team, were excluded.

Injury registration and athlete interviews

All interviews were conducted in person by physicians or physiotherapists from the Oslo Sport Trauma Research Centre (OSTRC) in the finishing area or during organized meetings at the competitor's hotels or Race office. A standardized interview form was used, outlined as the week by week calendar of the alpine WC, with the aim of facilitating athlete recall (Appendix 1). If the athlete reported an injury, a specific injury form was completed, including information concerning: (1) injury location, expressed as the body part injured, (2) injury side, (3) injury severity, expressed as number of days of absence from full participating in training and competition, (4) injury type, (5) injury circumstance and (6) specific diagnosis (Appendix 2). If the athlete was not present in person (due to injury or other reasons) interviews with their coaches, physicians or physiotherapists were conducted.

The definition of injury as well as the classification of the type of injury and body part injured is based on the consensus statement on injury surveillance in football (16). An injury is defined as "all injuries that occurred during training or competition and required attention by medical personnel" (16). Training included official training, other activity on snow and basic training not on snow (e.g. running, weightlifting or motoric training). The classification of the severity of the injuries is according to the duration of absence from training and competition which is as follows: slight (no absence), minimal (1 - 3 days), mild (4 - 7 days), moderate (8 - 28 days) and severe (>28 days) (16).

Exposure registration

To calculate exposure, the number of started runs during WC, WSC and Olympic Winter Games (OWG) competitions was counted manually for each athlete per competition. If an athlete did not finish or was disqualified from a run, we included the runs up to, as well as the run where the athlete did not finish or was disqualified. This information was obtained from the official FIS web site (17). The race calendar for each season was downloaded to identify the WC, WSC and OWG competitions. The number of runs for each athlete was summed per competition, per year and for the eight seasons.

Statistical analysis

The injury incidence was expressed as the absolute injury rate (the total number of injuries per 100 athletes per season) and the relative injury rate (the number of injuries per 1000 runs), both with their corresponding 95% confidence intervals (CI). The calculations were based on the Poisson model, and Z-tests were used for comparing injury incidences between seasons and computing the corresponding 95% CI. We computed risk ratio (RR) with their 95% CIs to compare the seasons before and after the change of ski regulations, the distribution with regard to body part injured and the injury risk between the different disciplines for all injuries. A two-tailed p level of <0.05 was considered statistically significant.

Video analysis of ACL-injuries

A team of five experts in field of skiing biomechanics and sports medicine related to alpine skiing analysed video recordings of ACL-injuries reported though the FIS ISS from the 2012-14 seasons. Videos of the injuries were obtained from the television producers of the FIS WC (Infront Media). They provided video footage of the entire run for each of the ACL injuries in the competition. By using a video editing programme (Adobe Premier Pro CS6, Adobe Systems Inc. San Jose, CA) the video recordings were edited to two different versions. One video of the entire run from start to where the athlete came to a complete stop and one short version showing the injury situation. Injury cases from the seasons after the new ski regulations (2012-14) were compared to the injury cases from six seasons prior to the change in equipment (2006-12). The analysis took place in a group session, were the injury cases were reviewed. The analysers were provided with information of each of the injury case extracted from the FIS ISS database. This information included, sex, injured side and discipline (DH, SG, GS or SL).

During the group session, the analysers identified the time of injury and reached a consensus, referred to as the index frame. After identifying the injury time point, the experts analysed the mechanisms for each case, using an analysis form developed during a previous study (5). The form included closed and open questions concerning (1) the circumstances of injury, (2) the skiing situation, (3) skier behaviour, and (4) joint angles and limb positions (Appendix 3). The entire run, as well as the short version showing the specific injury situation, was showed frame by frame during the group session. Each video of the injury cases was examined as many times as needed to obtain a consensus decision for all categorical variables. To obtain a consensus decision, at least three of the five experts had to agree. If fewer than three experts agreed, the variable was reported as ''no consensus.''

Results

Athlete interviews and injuries

During the eight seasons (2006-14), 2148 athlete interviews (951 in females and 1197 in males) were conducted and 724 injuries (279 in females and 445 in males) were reported (Table 1). Of these, 598 (83%) were time-loss injuries (absence ≥1 day) and 272 (38%) were severe injuries (absence >28 days).

In total, 44% (n=315) of the injuries took place during WC/WSC/OWG competitions, 17% (n=121) during official training to these competitions, and 10% (n=75) occurred during training related to other competitions (Table 1). Furthermore, 28% (n=201) of the injuries occurred in regular or team training on snow, and 1.7 % (n=12) during basic training not on snow.

Table 1: The number of athlete interviews and injuries reported during the eight seasons (2006–14) in WC alpine skiing.

	Seasons								
	06/07	**07/08**	**08/09**	**09/10**	**10/11**	**11/12**	**12/13**	**13/14**	**Total**
Interviews									
Female	116	113	115	128	118	118	124	119	951
Male	144	148	148	140	157	148	163	149	1197
Total	260	261	263	268	275	266	287	268	2148
Injuries									
WC/WSC/OWG	36	51	32	43	58	41	27	27	315
Official training to WC/WSC/OWG	11	19	19	21	18	13	12	8	121
Other competitions	1	0	0	0	0	1	0	0	2
Other FIS competition	12	10	4	3	11	5	11	8	64
Official FIS training	0	1	3	1	2	0	0	2	9
Other training activity on snow	24	24	29	23	37	24	26	14	201
Basic training not on snow	0	2	0	2	0	4	2	2	12
Information missing	0	0	0	0	0	0	0	0	0
Total	84	107	87	93	126	88	78	61	724

Injury incidences

In total, the absolute injury rate was 33.7 (95% CI 31.3 to 36.2) injuries per 100 athletes per season, higher in the six seasons before 36.7 (95% CI 33.7 to 39.7) the new ski regulations compared to the two seasons after 25.0 (95% CI 20.9 to 29.2; risk ratio (RR) 1.47 95% CI 1.22 to 1.77) (Table 2.). There was a significantly higher rate of severe injuries (>28 days absence) per 100 athletes per season before 13.0 (95% CI 11.2 to 14.8) than in the seasons after 8.0 (95% CI 6.1 to 10.0; RR 1.62 95% CI 1.22 to 2.14). The 2148 athletes entered a total of 36610 runs in the WC/OWG/WSC during the eight seasons (2006-14), including all disciplines (Table 2). Also, the relative injury rate (per 1000 runs) was higher six seasons before the change of regulations 9.5 (95% CI 8.3 to 10.6) compared to the two seasons after 5.9 (95% CI 4.3 to 7.5; RR 1.60, 95% CI 1.20 to 2.15). Including only the disciplines with change of equipment (DH, SG and GS), there was still a higher rate of injury before 12.6 (95% CI 10.9 to 14.3) the new regulations than after 8.0 (95 % CI 5.7 to 10.3; RR 1.57, 95% CI 1.15 to 2.15) (Table 3).

Table 2: Injuries, interviews, and exposure (number of runs) during eight seasons (2006-14) of the FIS Alpine World Cup with absolute injury rate (injuries per 100 athletes per season) and relative injury rate (injuries per 1000 runs) computed with 95% CI for the specific seasons.

	Per 100 Athlete Overall			**Per 1000 Runs WC/WSC/OWG**		
Season	**Injuries**	**Interviews**	**Incidence**	**Injuries**	**Runs**	**Incidence**
2006/07	84	260	32.3 (25.4-39.2)	36	4400	8.2 (5.5-10.9)
2007/08	107	261	41.0 (33.2-48.8)	51	4338	11.8 (8.5-15.0)
2008/09	87	263	33.1 (26.1-40.0)	32	4938	6.5 (4.2-8.7)
2009/10	93	268	34.7 (27.6-41.8)	43	4515	9.5 (6.7-12.4)
2010/11	126	275	45.8 (37.8-53.8)	58	4690	12.4 (9.2-15.5)
2011/12	88	266	33.1 (26.2-40.0)	41	4608	8.9 (6.2-11.6)
2012/13	78	287	27.2 (21.1-33.2)	27	4797	5.6 (3.5-7.8)
2013/14	61	268	22.8 (17.0-28.5)	27	4324	6,2 (3.9-8.6)
Total	724	2148	33.7 (31.3-36.2)	315	36610	8.6 (7.7-9.6)

Table 3: Number of injuries and runs six seasons before (2006-12) and two seasons after (2012-14) the change of regulations for equipment in the FIS Alpine World Cup with relative injury rate (injuries per 1000 runs) computed with 95% CI for each discipline.

	Injuries (n)		Exposure (runs)		Incidence (injuries per 1000 runs)			Risk ratio
Discipline	**2006-12**	**2012-14**	**2006-12**	**2012-14**	**2006-12**	**2012-14**	**Total**	**06-12 vs 12-14 (CI)**
Downhill	113	21	6241	1837	18.1 (14.8-21.4)	11.4 (6.5-16.3)	16.6 (13.8-19.4)	1.58 (0.99-2.52)
Super-G	49	10	4399	1281	11.1 (8.0-14.3)	7.8 (3.0-12.6)	10.4 (7.7-13.0)	1.43 (0.72-2.82)
Giant Slalom	59	16	6903	2749	8.5 (6.4-10.7)	5.8 (3.0-8.7)	7.8 (6.0-9.5)	1.47 (0.85-2.55)
Slalom	40	7	9946	3254	4.0 (2.8-5.3)	2.2 (0.6-3.7)	3.6 (2.5-4.6)	1.87 (0.84-4.17)
Total	261	54	27489	9121	9.5 (8.3-10.6)	5.9 (4.3-7.5)	8.6 (7.7-9.6)	1.60 (1.20-2.15)*

* Significant difference (p<0.05)

Regarding sexes, the total relative injury rate for males was higher before 11.4 (95% CI 9.7 to 13.2) compared to after the new regulations 6.9 (95% CI 4.5-9.3; RR 1.65 95% CI 1.13 to 2.41) while there was a non-significant change from 7.3 (95% CI 5.8-8.8) to 4.9 (95 % CI 2.9-7.0) per 1000 runs for females (Table 4.). The relative injury rate during the eight seasons was higher for males 10.3 (95% CI 8.9 to 11.8) than for females 6.7 (95% CI 5.5 to 7.9; RR 1.55 95 % CI 1.23 to 1.95).

Table 4: Number of injuries and runs for male and females six seasons before (2006-12) and two seasons after (2012-14) the new regulations for equipment in the FIS Alpine World Cup with relative injury rate (injuries per 1000 runs) computed with 95% CI for each sex.

	Injuries (n)		Exposure (runs)		Incidence (injuries per 1000 runs)			Risk ratio
Sex	**2006-12**	**2012-14**	**2006-12**	**2012-14**	**2006-12**	**2012-14**	**Total**	**06-12 vs 12-14 (CI)**
Male	167	32	14618	4633	11.4 (9.7-13.2)	6.9 (4.5-9.3)	10.3 (8.9-11.8)	1.65 (1.13-2.41)*
Female	94	22	12871	4488	7.3 (5.8-8.8)	4.9 (2.9-7.0)	6.7 (5.5-7.9)	1.49 (0.94-2.37)
Total	261	54	27489	9121	9.5 (8.3-10.6)	5.9 (4.3-7.5)	8.6 (7.7-9.6)	1.60 (1.20-2.15)*

* Significant difference (p<0.05)

Of all the injuries recorded, the most common injury location was the knee (40%), followed by the hand/finger/thumb (11%) and the head/face (9.5%). Injuries to the knee accounted for 42% of the injuries during competitions (2006-14), and of these 38% were ACL injuries. Overall, there was no difference in the absolute injury rate per 100 athletes in knee injuries before 13.8 (95% CI 12.0 to 15.6) compared to after the new regulations in equipment 11.7 (95% CI 8.9 to 14.6; RR 1.18 95% CI 0.89 to 1.56). For ACL injuries there was no difference in the absolute injury rate per 100 athletes. For both knee and ACL injuries, there was no significant difference in relative injury rate in the seasons before (2006-12) the new regulations compared to the seasons after (2012-13) (Figure 1). For both head injuries and severe (>28 days absence) head injuries, there was no difference in the absolute injury rate (per 100/athletes/season) between the seasons before and after.

Lower body injuries (injuries below the waist) accounted for 67% of all injuries and injuries to the upper body accounted for 33%. There was a significantly higher absolute injury rate among all injuries to the upper body before the new ski regulations 12.5 (95% CI 10.8 to 14.2) compared to after 6.7 (95% CI 4.5 to 8.8; RR 1.87 95% CI 1.32 to 2.66). A higher absolute injury rate was also found for all injures to the lower body before 24.2 (95% CI 21.8 to 26.6) compared to after the new regulations 18.4 (95% CI 14.8 to 21.9; RR 1.32 95% CI 1.06 to 1.64).

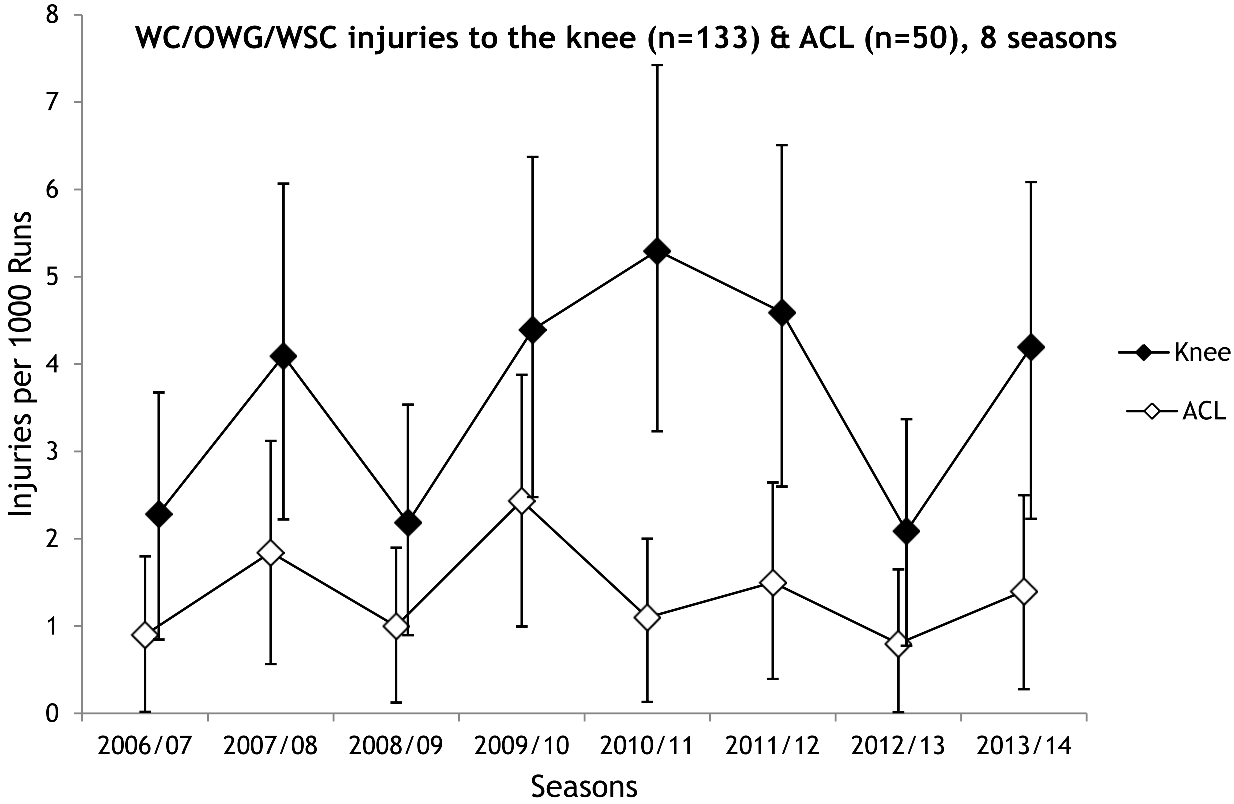

Figure 1: Number of knee and ACL injuries six seasons before (2006-12) and two seasons after (2012-14) the new regulations for equipment in the FIS Alpine World Cup with relative injury rate (injuries per 1000 runs) computed with 95% CI for each injury type.

Mechanisms of ACL injuries

Through FIS ISS, ten ACL injuries were registered from the WC competitions during the 2012-14 seasons (2012/13 n= 4, 2013/14 n=6). One of the situations was not reviewed as there was no footage of the actual injury. Of the nine, there were two injuries to the right knee and seven injuries to the left knee. There were three injuries in DH, two injuries in SG, two injuries in GS and two injuries in SL. The video analysis identified the following injury mechanisms: the `slip catch` (n=5), `dynamic snowplough` (n=1), the `landing back weighted` (n=2) and a valgus collapse injury (n=1). In six of the injury cases, the skier was turning at the time of the injury. The three remaining injury cases were injury situations during landing after a jump.

Discussion

This is the first study comparing injury rate and patterns before and after the implementation of new regulations of ski equipment in WC alpine skiing. The principal findings were that the absolute and relative rate of injuries overall was higher in the six seasons before the change of equipment compared to the two seasons after.

Injury incidence

We calculated the injury incidence as the absolute injury rate (number of injuries per 100 athletes per season) and as the relative injury rate (injuries per 1000 competition runs). We found an absolute injury rate of 33.7 and a relative injury rate of 8.6 during the eight seasons, which is similar to previous reports from FIS ISS for the 2006-12 seasons (2, 3). Regarding sex differences, we found that the relative injury rate during the eight seasons was higher for males than for females, which also corresponds to previous findings of sex differences in WC alpine skiing (2, 3). Furthermore, a lower rate of injuries was only found among males after the new ski regulations. This can be due to the fact that there are more males competing in the WC than females (56% males, 44% females), since the numerical reduction for females were similar.

We found no difference in each of the disciplines when comparing the relative injury rate before the new regulations for equipment to after. However, this is probably due to low power. When comparing the disciplines with new regulations together (DH, SG and GS), we found a 57% higher risk of overall injuries in the 2006-12 seasons compared to 2012-14. Low power should also be considered when interpreting the findings concerning ACL injuries. To find a significant difference, we would need to see considerably more ACL injuries, or study more seasons. However, the majority of knee and ACL injuries have been reported to occur while skiing, before or without falling. This is in contrast to most other injuries, which mainly occur as a result of crashes (18). We found that there was an 87% higher risk of injuries to the upper body during training and competitions in the seasons before the new ski regulations compared to after. Thus, one possible reason for the lower rate of injuries in the two seasons after the new regulations could be because of fewer crashes.

Regarding falls with injury, a study found 73% with impacts to the head (18). Prior to the 2013/14 season, new helmet standards were enforced by FIS (19). The new helmet standard in alpine skiing represented an attempt to reduce the rate of severe head injuries (20). Whether the new standard has had an effect on the rate of severe head injuries is unclear due to low study power, and needs to be further investigated.

The impact of new equipment

The results from our study suggest that the new ski regulations have had an effect on the overall rate of injuries. We know that the aim of the new ski regulations was to reduce the aggressiveness of the ski-snow interaction, provide a reduction in turning speed and forces, and reduce the risk of injuries (12). The background for the new regulations was based on previous FIS ISS reports, systematic video analyses of ACL injury mechanisms and interviews of experts (athletes, coaches, officials and equipment companies) (5, 9, 21). Experts suggested that aggressive skis and/or boots were the main equipment related contributor to injury events (22). They found it reasonable to assume that an aggressive ski may more easily `catch the edge` in out of balance situations (22). One could assume that the mechanisms of injuries would differ between the seasons before and after the new ski regulations. However, in most of the ACL-injuries analysed in this study, high forces acted on the knee after the skis `caught the edge` in out of balance situations. Although there was no difference in ACL injury mechanisms, we found however, a significant lower rate of severe injuries (>28 days absence) during training and competitions after the new regulations. These results further suggest that the less aggressive skis have had an effect on the rate of injuries.

The other proposed contributor to injury events were the ski boots, which were considered a risk factor because experts stated that the `boots were too stiff`(9). Due to regulation and enforcement problems, the ski boots were not evaluated by the prototype project (13). The different boot setup for each athlete in the WC and whether it influences the rate of injuries is unclear. It is found that, due to stiff materials and tight set up, the ski boots allow a high direct force transmission from the skis to the body and could therefore increase the risk of an ACL injury in e.g. landing back weighted situations (22, 23).

ACL injury mechanisms

We identified three distinct injury mechanisms through systematic video analysis of nine ACL injuries; the `slip catch`, `dynamic snow plough`, and the `landing back weighted`. Most of the injuries occurred while the skier was turning, and were in out of balance situations and the knee was forced into an internal rotation and/or valgus load. The ACL injury mechanisms identified in our study were similar to what Bere et al. (2011) described in their systematic video analysis (5).

The reasons for no differences in the rate and mechanisms of knee/ACL injuries might also be due to skier technique and strategy. A study suggested that skier errors, risk taking behaviour and inappropriate strategy were key factors leading to the injury situations, and these factors may be related to physical aspects (22). It seems reasonable to suggest that reduced physical fitness or fatigue may increase the risk of injury situations, influence the risk management and lead to poor tactical decisions. Bere et al. (2012) found, by video analysis of 69 injury situations that almost half of the injuries occurred in the final section of the course. The authors suggested that tiredness and lack of concentration might be an explanation. The combination of aggressive equipment and tough race conditions could sometimes be too much of a challenge for a tired skier (18)

Methodological considerations

During the eight WC seasons, the method of recording injuries was through interviews with athletes, coaches or team medical personnel at the end of each season. When using retrospective interviews, recall bias may be a challenge. There may have been a chance of underreporting minor injuries through the interviews, but for severe injuries e.g. ACL injuries, the consequence is of such a major impact that recall bias may not be an issue. A methodological study found retrospective athlete/coach interviews to be the best method to detect injuries during the season (15). Nevertheless, it should be taken into account that some of the injuries reported, severity and time of injury could be subject to error due to the method used. Another limitation is that we only recorded injuries through the WC winter seasons, and not during preseasons and summer training. We do not know the rate of injuries during off seasons.

The purpose of this study was to compare the injury rate, patterns and mechanism before and after the new ski regulations. Our approach to investigate the effect of the regulations could not rule out confounding factors, since the lower overall rate of injuries after the new ski regulations could possibly be due to the effects of other variables, e.g. course setting, snow conditions, tactical considerations, fatigue or skier experience. We did not take into account the rate of re-injuries among the athletes, due to methodological limitations of the study. In a study among football players, previous injury has been identified as one of the major risk factors for injury (24). A considerable strength of this study was that all athletes included were exposed to the change in ski regulations, as all the skiers need to comply with the rules in order to compete in the WC events.

WC alpine ski racers should direct focus on preventive training towards knee injuries based on the injury pattern observed in this study. It is unknown whether this would prove effective, but a meta-analysis regarding other sports found favourable estimates for active injury prevention measures (25). Continued injury surveillance for more WC seasons would give stronger data and could provide clarity of any effect of the ski regulations on the rate of knee and ACL injuries and the injury rate within the different disciplines.

Alpine ski racing requires a great variety of qualities for success. Ski and equipment together with skier technique and a skier's physical and mental strength are responsible for success in competitions (26). Difficulties would emerge, if trying to single out one factor predicting success. We assume the same thing for the prevention of injuries. Ski, equipment, course setting and snow conditions together with a variety of intrinsic factors, like experience, technique, specialization, physical and psychological factors, all may play a role in injury prevention in alpine ski racing. As suggested by Bahr and Krosshaug (2005), a multifactorial approach is needed to account for all factors involved (6). A modified sport-specific model as suggested by Raschner et al. (2012) is recommended as base for future investigation (27). Thus, further evaluation of risk factors is recommended and the development of preventive measures in alpine ski racing to reduce injuries, while ensuring the ski-ability of the equipment and the attractiveness of the sport.

Conclusion

The alpine ski racers were at 1.5 times the risk of sustaining an injury during the competitive seasons before the new ski regulations in the WC compared to the seasons after. The change in equipment therefore seems to have been a success.

What are the new findings?

- This is the first study of WC alpine skiing that has reported a significant difference in the overall injury rate among WC alpine ski racers before and after new regulations of ski equipment.
- The injury risk of severe (>28 days absence) and both upper and lower body injuries were lower after the new ski regulations.

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Ethics Approval

The project has been reported to the Regional Committee for Medical Research Ethics, South Eastern Norway Regional Health Authority, Norway and approved by the Social Science Data Services.

Competing Interests

None

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List of tables

Theory chapter

Article

List of figures

Theory chapter

Article

List of Appendices

Appendix 1

Injury Surveillance System - Interview
FIS World Cup Alpine 2014/15
Males

Athlete Name: Athlete : Male: □ Female: □

Nation: Discipline: Trainer:

Contact (e-mail/cell): MD/PT:

Comments	Date	Place	Nation	Discipline	Sex	Category	Injury
						Training	
	26.10.2014	**Soelden**	AUT	Giant Slalom	M	WC	
						Training	
	16.11.2014	**Levi**	FIN	Slalom	M	WC	
						Training	
	26.11.2014	**Lake Louise**	CAN	Downhill training	M	TRA	
Cancelled	27.11.2014	**Lake Louise**	CAN	Downhill training	M	TRA	
Cancelled	28.11.2014	**Lake Louise**	CAN	Downhill training	M	TRA	
	29.11.2014	**Lake Louise**	CAN	Downhill	M	WC	
	30.11.2014	**Lake Louise**	CAN	Super G	M	WC	
						Training	
	02.12.2014	**Beaver Creek**	USA	Downhill training	M	TRA	
	03.12.2014	**Beaver Creek**	USA	Downhill training	M	TRA	
Cancelled	04.12.2014	**Beaver Creek**	USA	Downhill training	M	TRA	
	05.12.2014	**Beaver Creek**	USA	Downhill	M	WC	
	06.12.2014	**Beaver Creek**	USA	Super G	M	WC	
	07.12.2014	**Beaver Creek**	USA	Giant Slalom	M	WC	
						Training	
Repl.: Val d Isere	12.12.2014	**Are**	SWE	Giant Slalom	M	WC	
Repl:: Val d Isere	14.12.2014	**Are**	SWE	Slalom	M	WC	
						Training	
	17.12.2014	**Val Gardena / Groeden**	ITA	Downhill training	M	TRA	
Cancelled	18.12.2014	**Val Gardena / Groeden**	ITA	Downhill training	M	TRA	
Replaces: 20.12.2014	19.12.2014	**Val Gardena / Groeden**	ITA	Downhill	M	WC	
Replaces: 19.12.2014	20.12.2014	**Val Gardena / Groeden**	ITA	Super G	M	WC	
						Training	
	21.12.2014	**Alta Badia**	ITA	GS	M	WC	
	21.12.2014	**Alta Badia**	ITA	Giant Slalom	M	WC	
						Training	
	22.12.2014	**Madonna di Campiglio**	ITA	Slalom	M	WC	
						Training	
	26.12.2014	**Santa Caterina**	ITA	Downhill training	M	TRA	
Cancelled	27.12.2014	**Santa Caterina**	ITA	Downhill training	M	TRA	
	28.12.2014	**Santa Caterina**	ITA	Downhill	M	WC	
						Training	
Cancelled	01.01.2015	**Muenchen**	GER	City Event	M	WC	
						Training	
	06.01.2015	**Zagreb**	CRO	Slalom	M	WC	
						Training	
	10.01.2015	**Adelboden**	SUI	Giant Slalom	M	WC	
	11.01.2015	**Adelboden**	SUI	Slalom	M	WC	

					Training		
	13.01.2015	**Wengen**	SUI	Downhill training	M	TRA	
Cancelled	14.01.2015	**Wengen**	SUI	Downhill training	M	TRA	
	15.01.2015	**Wengen**	SUI	Downhill training	M	TRA	
	16.01.2015	**Wengen**	SUI	Alpine combined	M	WC	
	16.01.2015	**Wengen**	SUI	Downhill	M	COM	
Rescheduled	17.01.2015	**Wengen**	SUI	Slalom	M	WC	
Rescheduled	18.01.2015	**Wengen**	SUI	Downhill	M	WC	
					Training		
	20.01.2015	**Kitzbuehel**	AUT	Downhill training	M	TRA	
Cancelled	21.01.2015	**Kitzbuehel**	AUT	Downhill training	M	TRA	
	22.01.2015	**Kitzbuehel**	AUT	Downhill training	M	TRA	
	23.01.2015	**Kitzbuehel**	AUT	Super G	M	WC	
	23.01.2015	**Kitzbuehel**	AUT	Alpine combined	M	WC	
	24.01.2015	**Kitzbuehel**	AUT	Downhill	M	WC	
	25.01.2015	**Kitzbuehel**	AUT	Slalom	M	WC	
					Training		
Night event	27.01.2015	**Schladming**	AUT	Slalom	M	WC	
					Training		
	03.02.2015	**Vail / Beaver Creek**	USA	Downhill training	M	TRA	
Replaces: 04.02.2015	05.02.2015	**Vail / Beaver Creek**	USA	Super G	M	WSC	
Cancelled	05.02.2015	**Vail / Beaver Creek**	USA	Downhill training	M	TRA	
	06.02.2015	**Vail / Beaver Creek**	USA	Downhill training	M	TRA	
	07.02.2015	**Vail / Beaver Creek**	USA	Downhill	M	WSC	
	08.02.2015	**Vail / Beaver Creek**	USA	Alpine combined	M	WSC	
	08.02.2015	**Vail / Beaver Creek**	USA	Downhill	M	COM	
	10.02.2015	**Vail / Beaver Creek**	USA	Team	A	WSC	
	12.02.2015	**Vail / Beaver Creek**	USA	Giant Slalom	M	FIS	
	13.02.2015	**Vail / Beaver Creek**	USA	Giant Slalom	M	WSC	
	14.02.2015	**Vail / Beaver Creek**	USA	Slalom	M	FIS	
	15.02.2015	**Vail / Beaver Creek**	USA	Slalom	M	WSC	
					Training		
	19.02.2015	**Saalbach**	AUT	Downhill training	M	TRA	
	20.02.2015	**Saalbach**	AUT	Downhill training	M	TRA	
	21.02.2015	**Saalbach**	AUT	Downhill	M	WC	
	22.02.2015	**Saalbach**	AUT	Super G	M	WC	
					Training		
	26.02.2015	**Garmisch Partenkirchen**	GER	Downhill training	M	TRA	
	27.02.2015	**Garmisch Partenkirchen**	GER	Downhill training	M	TRA	
	28.02.2015	**Garmisch Partenkirchen**	GER	Downhill	M	WC	
	01.03.2015	**Garmisch Partenkirchen**	GER	Giant Slalom	M	WC	
					Training		
	05.03.2015	**Kvitfjell**	NOR	Downhill training	M	TRA	
	06.03.2015	**Kvitfjell**	NOR	Downhill training	M	TRA	
	07.03.2015	**Kvitfjell**	NOR	Downhill	M	WC	
	08.03.2015	**Kvitfjell**	NOR	Super G	M	WC	
					Training		
	14.03.2015	**Kranjska Gora**	SLO	Giant Slalom	M	WC	
	15.03.2015	**Kranjska Gora**	SLO	Slalom	M	WC	
					Training		
	17.03.2015	**Meribel**	FRA	Downhill training	M	TRA	
	18.03.2015	**Meribel**	FRA	Downhill	M	WC	
	19.03.2015	**Meribel**	FRA	Super G	M	WC	
	20.03.2015	**Meribel**	FRA	Team	A	NGP	
	21.03.2015	**Meribel**	FRA	Giant Slalom	M	WC	
	22.03.2015	**Meribel**	FRA	Slalom	M	WC	
					Training		

Number of injuries: ________ Number of injury forms: ________

☐ The athlete has read and understood the Athlete Information form and consents to participate in the FIS Injury Surveillance System

Athlete signature

Appendix 2

F I S
PARTNER
FIS INJURY SURVEILLANCE SYSTEM

Injury Surveillance Study - World Cup Teams Interview

Oslo Sports Trauma

Injury report / *Verletzungsmeldung / Rapport de blessure*

Athlete information/
Informationen zum Athleten/Données sur l'athleète

Name/ *Name/Nom:* ☐

Country/ *Land/Pays*: ☐☐☐

Gender/ *Geschlecht/ Sexe:*
- ☐ Male/ *Mann/Homme*
- ☐ Female/ *Frau/Femme*

Injury information/
Information zur Verletzung/Information sur la blessure

Discipline: ☐

Injury 1 Date of injury: ☐

Body part injured/ *Verletzter Köperteil/Partie du corps blessée:*
- ☐ Head-face/ *Kopf-Gesicht/Tête-Face*
- ☐ Neck-cervical spine/ *Nacken-Halswirbel/Nuque-Vertèbre cervicale*
- ☐ Shoulder-clavicula/ *Schulter-Schlüsselbein/Epaule-Clavicule*
- ☐ Upper arm/ *Oberarm/Bras*
- ☐ Elbow/ *Ellbogen/Coudes*
- ☐ Forearm/ *Unterarm/Avant-bras*
- ☐ Wrist/ *Handgelenk/Poignet*
- ☐ Hand-finger-thumb/ *Hand-Finger-Daumen/Main-Doigt-Pouce*
- ☐ Chest (sternum-ribs-upper back)/ *Brustkasten (Brustbein-Rippen-Brustwirbelsäule)/Thorax (Sternum-Côtes-Haut du dos)*
- ☐ Abdomen/ *Bauch/Abdomen*
- ☐ Lower back-pelvis-sacrum/ *Lendenwirbelsäule-Becken-Kreuzbein/Bas du dos-Pelvis-Sacrum*
- ☐ Hip-groin/ *Hüfte-Leiste/Hanche-Aine*
- ☐ Thigh/ *Oberschenkel/Cuisse*
- ☐ Knee/ *Knie/Genoux*
- ☐ Lower leg-Achilles tendon/ *Unterschenkel-Achillessehne/Jambe-Tendon d'Achille*
- ☐ Ankle/ *Fussgelenk/Cheville*
- ☐ Foot-heel-toe/ *Fuss-Ferse-Zehen/Pied-Talon-Orteils*
- ☐ Information not available/ *Information nicht verfügbar/Information non disponible*

Did you use any protection?
- ☐ Helmet
- ☐ Back/ *Wirbelsäule/Dos*
- ☐ Shoulder/ *Schylter/Epaule*
- ☐ Elbow/ *Ellbogen/Coudes*
- ☐ Wrist/ *Handgelen/Poignet*
- ☐ Hip-pants
- ☐ Knee/ *Knie/Genoux*
- ☐ Leg-shin
- ☐ Teeth
- ☐ Pole-protection
- ☐ Jacket with different protection
- ☐ Other

Circumstances:
- ☐ FIS World Cup/World Championship(WCS)
- ☐ Other FIS competition
- ☐ Other competition
- ☐ Official FIS WC/WCS training
- ☐ Official FIS training
- ☐ Other training activity on snow
- ☐ Basic training, not on snow (weight lifting, running etc.)

Injury type/ *Art der Verletzung/Genre de la blessure:*
- ☐ Fractures and bone stress/ *Frakturen und Ermüdungsbrüche/Fracture et fracture de fatigue*
- ☐ Joint (non-bone) and ligament/ *Gelenke (nicht Knochen) und Bänder/Joint (articulation) et ligament*
- ☐ Muscle and tendon/ *Muskel und Sehnen/Muscle et tendon*
- ☐ Contusions/ *Quetschungen/Contusions*
- ☐ Laceration and skin lesion/ *Fleischwunden und Hautverletzung/Plaie et lésion de la peau*
- ☐ Nervous system including concussion/ *Nervensystem inkl. Gehirnerschütterung/Système nerveux y compris commotion cérébrale*
- ☐ Other/ *Andere/Autres*
- ☐ Information not available/ *Information nicht verfügbar/Information non disponible*

Absence from training and competition/ *Abwesenheit von Training und Wettkämpfen/Absence à l'entrainement et en compétitions:*
- ☐ No absence/ *Keine Absenz/Pas d'absence*
- ☐ 1 to 3 days/ *1 bis 3 Tage/1 à 3 jours*
- ☐ 4 to 7 days/ *4 bis 7 Tage/4 à 7 jours*
- ☐ 8 to 28 days/ *8 bis 28 Tage/8 à 28 jours*
- ☐ >28 days/ *>28 Tage/>28 jours*
- ☐ Information not available/ *Information nicht verfügbar/Information non disponible*

Side/ Seite/Part:
- ☐ Right/ *Rechts/Droite*
- ☐ Left/ *Links/Gauche*
- ☐ Not applicable/ *Nicht anwendbar/Non applicable*

Specific diagnosis/ *Genaue Diagnose/Diagnostic spécifique:*

☐

Please complete page 2/ *Bitte vervollständigen Sie Seite 2/Svp remplir page 2*

Injury information/
Information zur Verletzung/Information sur la blessure

Injury 2

Discipline:

Date of injury:

Circumstances:

- FIS World Cup/World Championship(WCS)
- Other FIS competition
- Other competition
- Official FIS WC/WCS training
- Official FIS training
- Other training activity on snow
- Basic training, not on snow (weight lifting, running etc.)

Body part injured/ *Verletzter Köperteil/Partie du corps blessée:*

- Head-face/ *Kopf-Gesicht/Tête-Face*
- Neck-cervical spine/ *Nacken-Halswirbel/Nuque-Vertèbre cervicale*
- Shoulder-clavicula/ *Schulter-Schlüsselbein/Epaule-Clavicule*
- Upper arm/ *Oberarm/Bras*
- Elbow/ *Ellbogen/Coudes*
- Forearm/ *Unterarm/Avant-bras*
- Wrist/ *Handgelenk/Poignet*
- Hand-finger-thumb/ *Hand-Finger-Daumen/Main-Doigt-Pouce*
- Chest (sternum-ribs-upper back)/ *Brustkasten (Brustbein-Rippen-Brustwirbelsäule)/Thorax (Sternum-Côtes-Haut du dos)*
- Abdomen/ *Bauch/Abdomen*
- Lower back-pelvis-sacrum/ *Lendenwirbelsäule-Becken-Kreuzbein/Bas du dos-Pelvis-Sacrum*
- Hip-groin/ *Hüfte-Leiste/Hanche-Aine*
- Thigh/ *Oberschenkel/Cuisse*
- Knee/ *Knie/Genoux*
- Lower leg-Achilles tendon/ *Unterschenkel-Achillessehne/Jambe-Tendon d'Achille*
- Ankle/ *Fussgelenk/Cheville*
- Foot-heel-toe/ *Fuss-Ferse-Zehen/Pied-Talon-Orteils*
- Information not available/ *Information nicht verfügbar/Information non disponible*

Injury type/ *Art der Verletzung/Genre de la blessure:*

- Fractures and bone stress/ *Frakturen und Ermüdungsbrüche/Fracture et fracture de fatigue*
- Joint (non-bone) and ligament/ *Gelenke (nicht Knochen) und Bänder/Joint (articulation) et ligament*
- Muscle and tendon/ *Muskel und Sehnen/Muscle et tendon*
- Contusions/ *Quetschungen/Contusions*
- Laceration and skin lesion/ *Fleischwunden und Hautverletzung/Plaie et lésion de la peau*
- Nervous system including concussion/ *Nervensystem inkl. Gehirnerschütterung/Système nerveux y compris commotion cérébrale*
- Other/ *Andere/Autres*
- Information not available/ *Information nicht verfügbar/Information non disponible*

Absence from training and competition/ *Abwesenheit von Training und Wettkämpfen/Absence à l'entrainement et en compétitions:*

- No absence/ Keine Absenz/Pas d'absence
- 1 to 3 days/ 1 bis 3 Tage/1 à 3 jours
- 4 to 7 days/ 4 bis 7 Tage/4 à 7 jours
- 8 to 28 days/ 8 bis 28 Tage/8 à 28 jours
- >28 days/ >28 Tage/>28 jours
- Information not available/ *Information nicht verfügbar/Information non disponible*

Side/ Seite/Part:

- Right/ *Rechts/Droite*
- Left/ *Links/Gauche*
- Not applicable/ *Nicht anwendbar/Non applicable*

Did you use any protection?

- Helmet
- Back/ *Wirbelsäule/Dos*
- Shoulder/ *Schylter/Epaule*
- Elbow/ *Ellbogen/Coudes*
- Wrist/ *Handgelen/Poignet*
- Hip-pants
- Knee/ *Knie/Genoux*
- Leg-shin
- Teeth
- Pole-protection
- Jacket with different protection
- Other

Specific diagnosis/ *Genaue Diagnose/Diagnostic spécifique:*

Appendix 3

Oslo Sports Trauma
RESEARCH CENTER

FIS
PARTNER
FIS INJURY SURVEILLANCE SYSTEM

Description of ACL tear in World Cup alpine skiing

Analyst: Date:

A. INJURY INFORMATION

Injury nr: ________ Specific diagnosis: ________

Male: ________ Right knee: ________ Competition: ________

Female: ________ Left knee: ________ Off. trainng: ________

Discipline: Downhill ________
Super G ________
Giant slalom ________
Slalom ________

Index frame number (consensus):
Alternative index frame number(s):
Corresponding index frame(s)
De-interlaced index frame number(s):
Comment:

B. PRECEDING THE INJURY

Skiing situation:

Visibility:
Good ☐
Reduced ☐
Unsure ☐

Type of terrain:
Flat ☐
Medium ☐
Steep ☐
Flat to steep ☐
Steep to flat/compression ☐
Dosed ☐
Unsure ☐

Snow condition:
Icy ☐
Hard ☐
Soft ☐
Unsure ☐

Weather condition:
Clear ☐
Foggy ☐
Snowy ☐
Unsure ☐

Piste condition:
Smooth ☐
Rough/bumpy ☐
Changes frequently ☐
Unsure ☐

The skier is:
Turning ☐
Gliding/straight skiing ☐
Traversing ☐

If, turning, the skier is in:
Initiation phase ☐
Steering phase into fall line ☐

Jumping - take off	☐	Steering phase out of fall line	☐
Landing after a jump	☐	Change of turns	☐
Unsure	☐	Unsure	☐

Gate contact:

High influence on the following loss of control	☐
Slight influence on the following loss of control	☐
Skier has already lost control before gate contact	☐
Yes, but no influence on the injury situation	☐
No gate contact	☐
Unsure	☐

Has the skier lost control (is out of balance) before time of injury?

Yes ☐
No ☐
Unsure ☐

If yes:
Crash ☐
Major instability ☐
Minor instability ☐
Unsure ☐

If turning:

Which knee is the injured side?
Outer ski ☐
Inner ski ☐

The skier is:

Out of balance backward	☐
Out of balance forward	☐
Out of balance inward	☐
Out of balance backward/inward	☐
Out of balance outward	☐
In balance in the sagittal plane	☐
Unsure	☐

Outer ski is carving	☐
Outer ski is drifting	☐
"Slip-catch" situation	☐
Unsure	☐
Inner ski is carving	☐
Inner ski is drifting	☐
"Slip-catch" situation	☐
Unsure	☐

The skier is:

Overrotating in relation to turn radius	☐
Underrotating in relation to turn radius	☐
In balance in the transversal plane	☐
Unsure	☐

The weight distribution is:

Mainly on outer ski	☐
Mainly on inner ski	☐
Equally on both skies	☐
Unsure	☐

If not turning:

The skier is:

Out of balance backward	☐
Out of balance forward	☐
In balance in the sagittal plane	☐
Unsure	☐
Out of balance to the right	☐
Out of balance to the left	☐
In balance in the frontal plane	☐

The weight distribution is:

Mainly on right ski	☐
Mainly on left ski	☐
Equally on both skies	☐

:

Unsure ☐ Unsure ☐ ☐

Which knee is the injured side?

Right ski ☐

Left ski ☐

Right ski is carving in	☐	Left ski is carving in	☐	☐
Right ski is carving out	☐	Left ski is carving out	☐	☐
Right ski is drifting in	☐	Left ski is drifting in	☐	☐
Right ski is drifting out	☐	Left ski is drifting out	☐	☐
Right ski is straight forward	☐	Left ski is straight forward	☐	☐
Unsure	☐	Unsure	☐	☐
				☐

Please describe the skiing situation preceding the injury in your own words, outlining any factors which may cause the injury situation. ☐

☐
☐
☐
☐
☐
☐
☐
☐
☐
☐ ☐ ☐

C. THE TIME OF INJURY (INDEX FRAME REFERENCE)

4-5 frames prior to the index frame, the skier is :

Still trying to regain balance	☐
Giving up regaining balance	☐
Already out of balance	☐
In balance	☐
Unsure	☐

Knee movements (during the last 4-5 frames prior to the index frame):

	Injured side	Non injured side	
Toward flexion	☐	☐	☐
Toward extension	☐	☐	☐
Static	☐	☐	☐
Unsure	☐	☐	
			☐
Tibia externally rotating	☐	☐	☐
Tibia internally rotating	☐	☐	☐
Static	☐	☐	☐
Unsure	☐	☐	
			☐
Toward valgus	☐	☐	☐
Toward varus	☐	☐	☐
Static	☐	☐	☐
Unsure	☐	☐	

Hip movements (during the last 4-5 frames prior to the index frame):

	Injured side	Non injured side
Toward flexion	☐	☐

Toward extension	☐	☐
Static	☐	☐
Unsure	☐	☐
Externally rotating the thigh	☐	☐
Internally rotating the thigh	☐	☐
Static	☐	☐
Unsure	☐	☐
Adducting	☐	☐
Abducting	☐	☐
Static	☐	☐
Unsure	☐	☐

☐

Angles of Knee position (at the index injury frame) related to the anatomical neutral position:

	Injured side		Non injured side	
	Knee angle	Unsure	Knee angle	Unsure
Flexion/extension (+/-) straight knee = 0	_________	☐	_________	☐
External/internal rotation (+/-)	_________	☐	_________	☐
Valgus/varus (+/-)	_________	☐	_________	☐

☐

Angles of Hip position (at the index frame) related to the anatomical neutral position:

	Injured side		Non injured side	
	Hip angle	Unsure	Hip angle	Unsure
Flexion/extension (+/-)	_________	☐	_________	☐
External/internal rotation (+/-)	_________	☐	_________	☐
Abduction/adduction (+/-)	_________	☐	_________	☐

☐

Position of the arms (at the index frame) related to the upper body/truncus:

	Right arm	Left arm
Forward (shoulder flexion)	☐	☐
Backward (shoulder extension)	☐	☐
Neutral position	☐	☐
Unsure	☐	☐
Outward (shoulder abduction)	☐	☐
Inward (shoulder adduction)	☐	☐
Neutral position	☐	☐
Unsure	☐	☐

☐

Ground contact between the ski and the snow (at the index frame):

	Injured side		Non injured side	
	Yes	No	Yes	No
The tail of the ski	☐	☐	☐	☐
The tip of the ski	☐	☐	☐	☐
The whole length of the ski	☐	☐	☐	☐
No contact	☐	☐	☐	☐
Unsure	☐	☐	☐	☐
If contact:	Yes	No	Yes	No
The inside edge of the ski	☐	☐	☐	☐
The outside egde of the ski	☐	☐	☐	☐
The whole width of the ski	☐	☐	☐	☐
Unsure	☐	☐	☐	☐

Binding release during the injury situation: ☐		
	Injured side	Non injured side
Before the ACL is torn	☐	☐
After the ACL is torn	☐	☐
No release	☐	☐
Unsure	☐	☐

Please describe the injury mechanism in your own words.

THE TIME OF INJURY (ALTERNATIVE INDEX FRAME REFERENCE)

4-5 frames prior to the index frame, the skier is :

Still trying to regain balance	☐
Giving up regaining balance	☐
Already out of balance	☐
In balance	☐
Unsure	☐

Knee movements (during the last 4-5 frames prior to the index frame):

	Injured side	Non injured side	
Toward flexion	☐	☐	☐
Toward extension	☐	☐	☐
Static	☐	☐	☐
Unsure	☐	☐	
			☐
Tibia externally rotating	☐	☐	☐
Tibia internally rotating	☐	☐	☐
Static	☐	☐	☐
Unsure	☐	☐	
			☐
Toward valgus	☐	☐	☐
Toward varus	☐	☐	☐
Static	☐	☐	☐
Unsure	☐	☐	

Hip movements (during the last 4-5 frames prior to the index frame):

	Injured side	Non injured side
Toward flexion	☐	☐
Toward extension	☐	☐
Static	☐	☐
Unsure	☐	☐
Externally rotating the thigh	☐	☐
Internally rotating the thigh	☐	☐

Static	□	□
Unsure	□	□
Adducting	□	□
Abducting	□	□
Static	□	□
Unsure	□	□

□

Angles of Knee position (at the index injury frame) related to the anatomical neutral position:

	Injured side		Non injured side	
	Knee angle	Unsure	Knee angle	Unsure
Flexion/extension (+/-) straight knee = 0	_________	□	_________	□
External/internal rotation (+/-)	_________	□	_________	□
Valgus/varus (+/-)	_________	□	_________	□

□

Angles of Hip position (at the index frame) related to the anatomical neutral position:

	Injured side		Non injured side	
	Hip angle	Unsure	Hip angle	Unsure
Flexion/extension (+/-)	_________	□	_________	□
External/internal rotation (+/-)	_________	□	_________	□
Abduction/adduction (+/-)	_________	□	_________	□

□

Position of the arms (at the index frame) related to the upper body/truncus:

	Right arm	Left arm
Forward (shoulder flexion)	□	□
Backward (shoulder extension)	□	□
Neutral position	□	□
Unsure	□	□
Outward (shoulder abduction)	□	□
Inward (shoulder adduction)	□	□
Neutral position	□	□
Unsure	□	□

□

Ground contact between the ski and the snow (at the index frame):

	Injured side		Non injured side	
	Yes	No	Yes	No
The tail of the ski	□	□	□	□
The tip of the ski	□	□	□	□
The whole length of the ski	□	□	□	□
No contact	□	□	□	□
Unsure	□	□	□	□
If contact:	Yes	No	Yes	No
The inside edge of the ski	□	□	□	□
The outside egde of the ski	□	□	□	□
The whole width of the ski	□	□	□	□
Unsure	□	□	□	□

Binding release during the □

injury situation:		
	Injured side	Non injured side
Before the ACL is torn	☐	☐
After the ACL is torn	☐	☐
No release	☐	☐
Unsure	☐	☐

Please describe the injury mechanism in your own words.		
	☐	☐