

Injury surveillance to implementation:  
Strategies to ameliorate alpine skiing and  
snowboarding injuries in New Zealand

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A thesis submitted to the Auckland University of Technology in  
fulfilment of the requirements for the degree of the  
Doctor of Philosophy (PhD)

School of Sport and Recreation

This thesis is dedicated to all who recreate in the mountains, marvel at the snowflake, take energy from the carving turn, and pause to appreciate the majestic, keep safe.

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## ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any degree or diploma of a university or other institution of higher learning.

A handwritten signature in black ink that reads "Brenda Costa-Scorse". The signature is written in a cursive style with a large initial 'B' and a long, sweeping underline.

Brenda Costa-Scorse

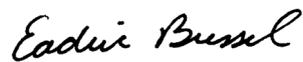
12 September 2017

## CO-AUTHORED PUBLICATIONS

Chapter 3 to 5 have resulted in four published manuscripts. Chapter 7 has resulted in a published monograph. The co-authored publications table details the author contributions. All co-authors have approved the inclusion of these manuscripts in this doctoral thesis. The executive director of Ski Areas Association New Zealand (SAANZ) has approved inclusion of all industry outputs that arose from this thesis.

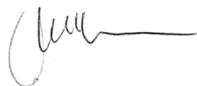


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Chapter	Publication reference	Contribution
<b>Chapter 3</b>	Costa-Scorse, B. A., Hopkins, W. G., Cronin, J. & Bressel, B. (2015). The utility of two national injury databases to evaluate snow sports injuries in New Zealand. <i>Snow Sports Trauma and Safety: 21<sup>st</sup> Volume</i> . Cham: Springer International Publishing. DOI: 10.1007/978-3-319-52755-0_4	
<i>Contribution</i>	BCS- Ethics, statistical analysis, writing manuscript. WH- Guidance in statistical analysis and manuscript review. JC- Advice for discussion and interpretation of the findings. EB- Advice for discussion and interpretation of the findings.	BCS 80% WH 16% JC 2% EB 2%
	Costa-Scorse, B. A., Hopkins, W. G., Cronin, J. & Bressel, B. (2016). Injuries in alpine skiing and snowboarding at New Zealand ski areas over five winter seasons (2010 – 2014). <i>Snow Sports Trauma and Safety: 21<sup>st</sup> Volume</i> . Cham: Springer International Publishing. DOI: 10.1007/978-3-319-52755-0_2	
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<i>Contribution</i>	BCS- Ethics, data collection, statistical analysis, manuscript.	BCS 90%
	WH- Guidance in statistical analysis and manuscript review.	WH 4%
	RB- Advice for discussion and interpretation of the findings.	RB 4%
	ML- Advice for discussion and interpretation of the findings.	ML 2%

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**Chapter 5** Costa-Scorse, B. A., Hopkins, W. G., & Bahr, R. (2015). Evaluation of ski-binding-boot system safety using torque-testing. *Skiing Trauma and Safety: 20<sup>th</sup> Volume*. Philadelphia: ASTM International. DOI:10.1520/STP158220140009

<i>Contribution</i>	BCS- Ethics, data collection, analysis, writing manuscript.	BCS 92%
	WH- Guidance in statistical analysis and manuscript review	WH 4%
	RB- Advice for discussion and interpretation of the findings.	RB 4%

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<i>Contribution</i>	BCS- Ethics, data collection, consultation, writing monograph.	BCS 90%
	MD, AH, MD, PCB, ML, JC, JB, WGH - Guidance in monograph review.	et al. 10%

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## ABSTRACT

Snow sports injuries in New Zealand cost the government no-fault insurance scheme \$20.5 million in 2014, accounting for 5% of sport and recreation claims. Cost in terms of quality of life may be much greater, as an individual's well-being potentially affected by injury over months or years. The question of interest in this thesis centred on finding strategies to ameliorate such injuries. Review of the literature (Chapter 2, 5, 7) describes aetiology, injury mechanisms, the playing surface, equipment standards and injury prevention strategy development processes. To formulate strategy an injury prevention model Translating Research into Injury Prevention Practice (TRIPP) six-stage framework underpins thesis progression from epidemiological to experimental studies to injury-prevention strategy implementation.

Chapter 3 injury surveillance, describes the size and nature of the injury problem in alpine skiing and snowboarding. Analysis of ski area National Incident Data (NID) determined New Zealand injury rates of 3.2, 3.3, 3.4, 2.7 and 3.1 per 1000 skier/boarder days respectively (2010 – 2014). Two-thirds of first injury presentations, mostly sprains, bypassed mountain clinics; important information for determining targeted injury prevention programmes. Knee injury commonly occurred, more in skiers than snowboarders or tubing/hiking: 76%, 21%, and 3% respectively. Intermediate skiers were 1.6 times more likely to sustain a knee injury with non-release of ski-bindings in hard and soft snow.

Chapter 4 (TRIPP stage 2) aimed to determine factors that may impede ski-binding release. Analysis of standards of practice found only 10% of ski technicians met international standards. Torque testing to mitigate the risk of binding malfunction or incorrect set-up was uncommon. Over a third of the time, weight, an essential characteristic for the accurate determination of release values was not acquired.

Chapter 5 established equipment risk via random torque tests. Class III deviations  $\pm 45\%$  from the tolerance threshold for release warranting removal (8%) and Class II (48%) deviations  $\pm 30\%$  to  $\pm 45\%$  needed corrective action. Ski-binding heelpieces with two or more seasons use were nine times more likely to be out of

tolerance than those with only one season of use. The common industry practice of retiring rental skis after three or four seasons' use was an inadequate safety measure.

Binding self-release manoeuvres and self-adjustments identified as possible alternative solutions to increased labour and torque-testing plant costs, was the focus of experimental Chapter 6. Recreational skiers 14 years and over performed tests in ideal conditions (TRIPP stage 4). Of those that self-released only 28% released on ISO recommended release torques, all other skiers only released when the ski-binding settings were lighter than recommended. Additionally, there was no easy to use ski-boot wear and tear grading system highlighting a gap in existing standards.

Chapter 7 described the mountain implementation context (TRIPP stage 5) and detailed strategy implementation (TRIPP stage 6). The five-year injury prevention strategy developed in the thesis adopted by Ski Areas Association New Zealand will harness injury prevention efforts going forward. The new snow safety code, a completed first year strategy action seeks to address part of the injury prevention puzzle.

## CHAPTER 1 - INTRODUCTION

### 1.1 Rationale

Treating injured individuals is a privileged trusted space that often brings satisfaction when part of hastening recovery, and enormous sadness when the survival odds are stacked against the person. Questions in this thesis formed as a ski patroller over eighteen winter seasons where multiple mountain rescues fuelled determination to help change the status quo. It is my belief that people that recreate in the mountains should leave ski areas having enjoyed their day inspired by viewing life from the peaks not an ambulance. This thesis anchored by the premise, many injuries are preventable, sought to determine strategies that can ameliorate skiing and snowboarding injuries in New Zealand.

Snow sports injuries reported in the New Zealand Accident Compensation Commission (ACC) no-fault government insurance scheme equated to approximately 5% of the sport and recreation claims, with a cost of \$20.5 million in 2014 (1). In dollar terms, clearly alpine skiing and snowboarding injuries were a public health burden warranting investment in evidence-based solutions (2, 3). However, what constituted a snow sports injury in the ACC data was unclear. Broader injury definitions existed, any damage to the body caused by acute exposure to physical agents that exceeded the threshold of human tolerance (2, 4). Sports injury definition included competitive or recreational activity where the pastime required physical effort (5, 6). Snow sports injuries met sport and general injury criteria, however, current description of the size and nature of the skiing and snowboarding injury problem in New Zealand was lacking. Understanding the magnitude of the problem provided the initial focus of this thesis.

Snow sports injury rates at New Zealand ski areas in the 1989 and 1990 winter seasons were 4.5 and 3.3 per 1000 skier days respectively, with knee medial collateral ligament injuries one-sixth of all injuries (7). Unspecified knee trauma over these two seasons indicated knee injury could be a far larger problem. No published data existed for subsequent years describing New Zealand knee injury trends. Longitudinal case control studies in Vermont USA found serious grade III knee sprains injuries involving the anterior cruciate ligament had a net increase of 121%

in the period 1972 – 2006 (8). Similar findings were found in France and Norway; notably, female skiers were three times more likely to have grade III knee injuries with anterior cruciate ligament rupture than male skiers (9, 10). The initial decline of fractured tibias' seen with the introduction of recommended release values for ski bindings based on skier characteristics had plateaued (8, 11). There was no local data on application of equipment standards. The locus of control of injuries clearly was not solely the responsibility of injured individuals but could include the system that exposed people to unnecessary risk of harm (6, 12, 13). In order to develop solutions host-agent-environment root causes needed specifying. Limited empirical evidence existed on ski-binding safety testing with self-release manoeuvres. Other than the knee, New Zealand incident data (1989 - 1990) highlighted that thumb, head lacerations and concussion were common (7). Local alpine skiing injury patterns in recent decades were unknown. Snowboarding was not in existence in the era studied so patterns of injury in this sport for New Zealand were unknown.

Finally, there was limited data on injury prevention strategic development specific to snow sports. The only published injury prevention message from Ski Areas Association New Zealand was the New Zealand Snow Users' Responsibility Code, last reviewed in 2004 (14). The code did not promote protective equipment. The efficacy of helmet wear, wrist protectors, knee and back protectors was needed to inform national injury prevention actions. Knowledge gaps to be addressed in this thesis

## **1.2 Objectives**

The limitations and gaps in the knowledge identified in the introduction pertaining to New Zealand skiing injuries, snowboarding injuries, and safety in snow sports informed the objectives of this thesis. These were:

- I. Expand injury surveillance at all New Zealand ski areas.
- II. Describe the magnitude and nature of the skiing and snowboarding injury problem.
- III. Review standards of practice.
- IV. Investigate ski equipment risk.
- V. Assess a proposed intervention under controlled conditions.
- VI. Develop evidence-based solutions.

### 1.3 Methods

Centred on injury prevention in alpine skiing and snowboarding in New Zealand, the thesis follows the six stages of the TRIPP framework: injury surveillance; causation; identification of possible solutions; assessment of proposed interventions in ideal controlled conditions; description of the intervention context; and implementation and evaluation of interventions (15). Application of the injury prevention model formulated by Finch (2006) helps determine the studies required in the development of a national injury prevention strategy.

This first chapter provides the rationale, objectives, methodological approach, outline and significance of the thesis. The literature in Chapter 2 positions the reader for what follows. Chapters 3, 4, 5 and 6 involved human subjects and as such required ethical approval from the Auckland University of Technology Ethics Committee (see, Appendix I). Two epidemiological studies presented in Chapter 3 describe the New Zealand snow sports injury problem (TRIPP stage one). Both Chapters 4 and 5 address equipment-related causation (TRIPP stage two). A cross-sectional study of rental workers and key personnel examines systems risk in Chapter 4. Chapter 5 focuses on a single aspect of risk with an experimental study of ski equipment and identifies possible solutions (TRIPP stage three). Chapter 6 tests a potential solution for equipment-related injury under ideal conditions at an indoor snow dome (TRIPP stage four). Chapter 7 describes the mountain context (TRIPP stage five) using a literature review, survey data, and a focus group. Development of a national injury prevention strategy and new snow safety code meets the implementation requisites of TRIPP stage six. Finally, in Chapter 8, practical applications are summarised, and future research opportunities for evaluation of the strategy are identified (TRIPP stage six).

Chapters 3 to 5 consist of published manuscripts. A published monograph and new safety code are included in Chapter 7. Chapters 3 – 7 resulted in four international conference presentations and four Ski Areas Association New Zealand conference presentations.

## 1.4 Thesis Outline

The overarching question of the thesis is addressed in eight chapters outlined in Figure 1.1 organized sequentially in TRIPP stages.

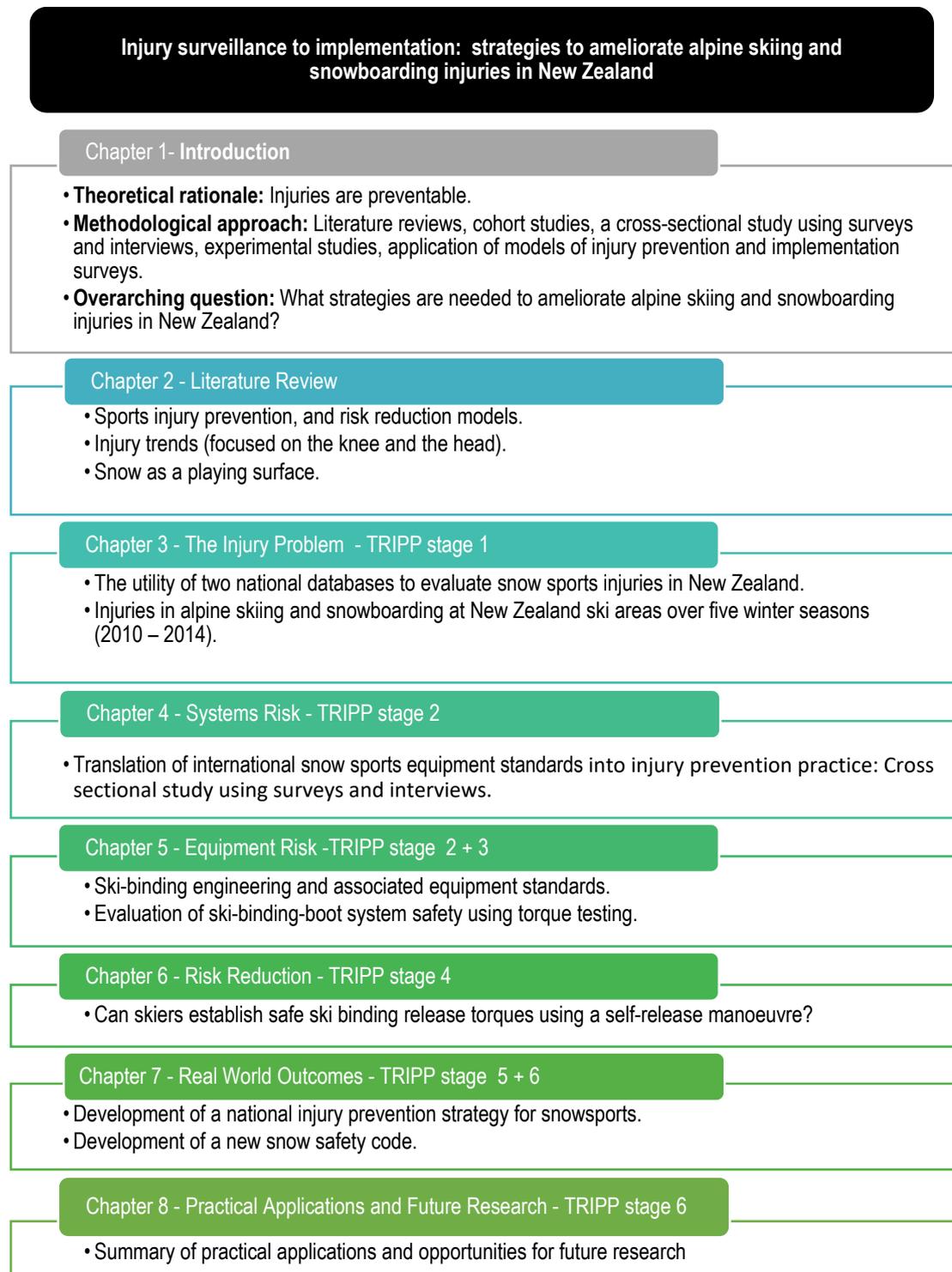


Figure 1.1: Thesis outline.

## **1.5 Significance of thesis**

This thesis lays foundations and focus for future injury-prevention interventions in alpine skiing and snowboarding in New Zealand. Epidemiological data will provide essential baseline measures for future snow sports injury prevention research. The effect of snow surface conditions, visibility, ability and ski-binding release will add to causation data. New understandings of systems and equipment-related risk in the set-up of alpine skis will inform changes in practice. Examination of the ski-binding self-release test will increase understanding of ski-binding-boot system safe set-up. This thesis will contribute to advances in international safety standards and dissemination. The findings that arise from this thesis may provide other alpine sporting nations with a new approach to snow sports injury-prevention strategy development. Importantly, this thesis will contribute actionable evidence to help ameliorate alpine skiing and snowboarding injuries in New Zealand.

## 1.6 Ethics Approval

Ethics approval for the thesis was granted by the Auckland University of Technology ethics committee (AUTEK) in 2014 for a period of three years (see, Appendix I).

- # 14/146 ACC Client Cohort Study
- # 14/53 Ski-Binding Release

## CHAPTER 2 - LITERATURE REVIEW

### 2.1 Introduction

Preventing injurious events is clearly preferable to suffering from such incidents (16). Injury may lead to lost days at work, financial pressures, slow progress in academic studies, and limit sporting activity (17). Navigating the potentially convoluted battle to recover may also affect an injured person's future aspirations, decrease participation in physical activity and in-turn this lack of activity could undermine well-being. Adding to the post-injury recovery challenges the psycho-social impact of injury has also been associated with depression (18). At the outset of this thesis the World Health Organisation Ottawa Charter call to enable people to mediate and advocate for good health resonated (19). The data in this narrative review informs the epidemiological and experimental studies. All elements of this thesis inform the national injury prevention strategy and the action plans within the strategy that advocate for change in the status quo. The review of literature is presented in three sections: 1) sports injury prevention and risk reduction models; 2) injurious events (focused on the knee and the head) and, 3) snow as a playing surface. The literature search and selection overview is provided in Figure 2.1.

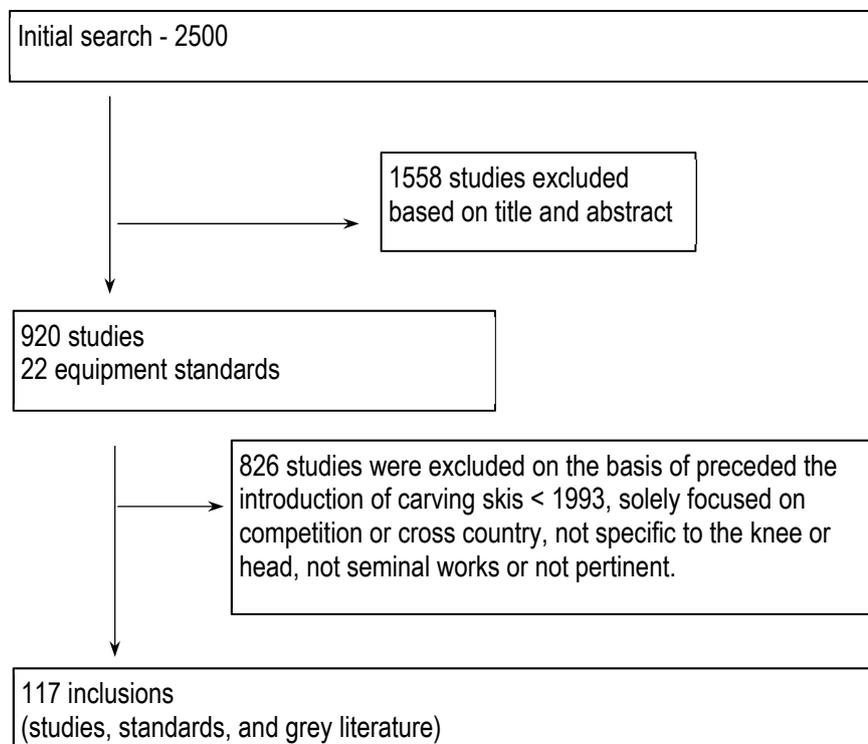


Figure 2.1: Schematic representation of systematic search and selection.

## 2.2 Methods

Database searches were systematically performed using Google Scholar, Scopus, Sport Discus and Medline for studies related to alpine skiing, snowboarding and injury prevention published in English from 1990 using Boolean operators AND/OR and key words: skiing, snowboarding, injury, knee, head, prevention, models, snow, equipment, and standards. Regardless of year anthologies of the symposium 'Skiing Trauma & Safety I – XXI were considered. Seminal works related to injury prevention and risk management, grey literature, government documents and equipment standards (translated to English) also were considered. Exclusion criteria: all articles pre-carving ski era (<1993) checked for application in the new equipment environment (ski design changes included shorter ski lengths and side-wall changes that altered the turning radius) before exclusion. Cross country and competitive snow sports research also checked for applicability to the downhill recreational snow sports environment; where there was no cross-over these data were excluded.

## 2.3 Results/Discussion:

### **Sports injury prevention and risk reduction models**

One of the first questions requiring an answer at the commencement of the thesis was which injury prevention model(s) would provide the schema to determine injury trends, identify risks in alpine skiing and snowboarding, and ultimately assist in determining the targeted injury prevention programs for New Zealand? To answer this question, a brief treatise of the evolution and construction of injury prevention models was undertaken.

Sports injury prevention models originated out of the public health arena and were designed to help researchers provide evidence for injury prevention interventions (15, 17). The 1987 "Sequence of Prevention" proposed by van Mechelen, Hlobil and Kemper of the Netherlands National Institute for Sports Care (17, 20) affirmed injury prevention efforts in sport (see Figure 2.2). This model created a pioneering platform for developers of other sports injury prevention models. The four steps in the van Mechelen "Sequence of Injury Prevention Model" can be likened to a quality improvement cycle of consecutive steps that provide a measured exploration of the injury problem and possible solutions. The cycle is repeated until complete resolution of the problem has occurred.

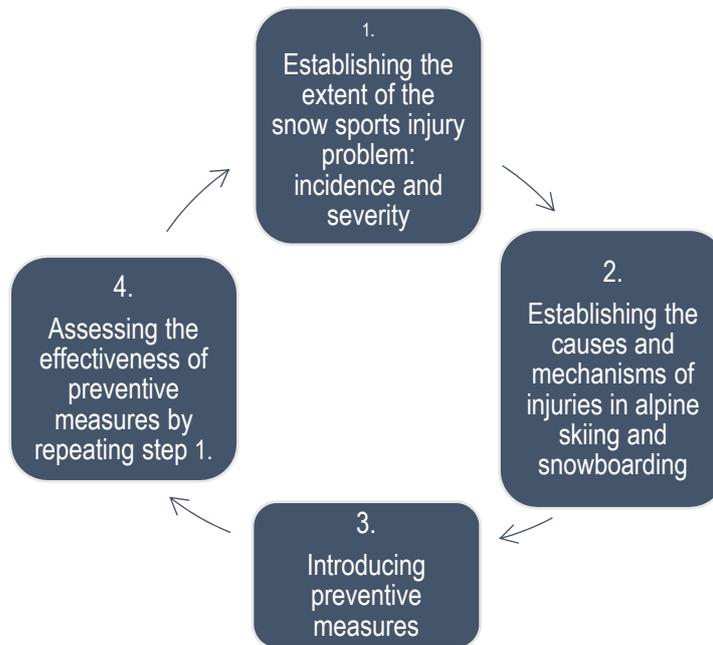


Figure 2.2: Sequence of injury prevention model (adapted from van Mechelen et al., 1987).

To sort through the maze of internal and external factors associated with injury in sport, Meeuwisse from the University of Calgary Sport Injury Prevention Research Group created the “Assessing Causation in Sport Injury: a Multifactorial Model” (21). This model, published in 1994 sought to improve descriptions of the aetiology of sports injury. The catalysts for injury when skiing or snowboarding generally have more than one cause. For example, causes of injury could be heavy snow, poor visibility, and inadequate skills for the snow surface conditions, ski-binding release settings that are set too high, no helmet to protect the head in a fall, or poorly designed trail merges that increase the risk of collision. Internal risk factors in the heavy snow injury scenario could include poorly developed quadriceps to cope with the physical demands of the snow surface conditions and/or diminished visual acuity to accurately read and respond to the changing contour of the terrain. Stating that any of the aforementioned injury risk factors are the cause of an injury from an observed association is fraught with no statistical association, or when statistically associated factors are either associated or have a secondary non-causal association.

Improvements of determination of the cause or causes of injury in sport were championed by Bahr and Krosshaug from the Oslo Sports Trauma Research

Centre (22). More precise descriptions on predisposition, susceptibility to injury and the inciting event were required in their “Comprehensive Model for Injury Causation” (see Figure 2.3).

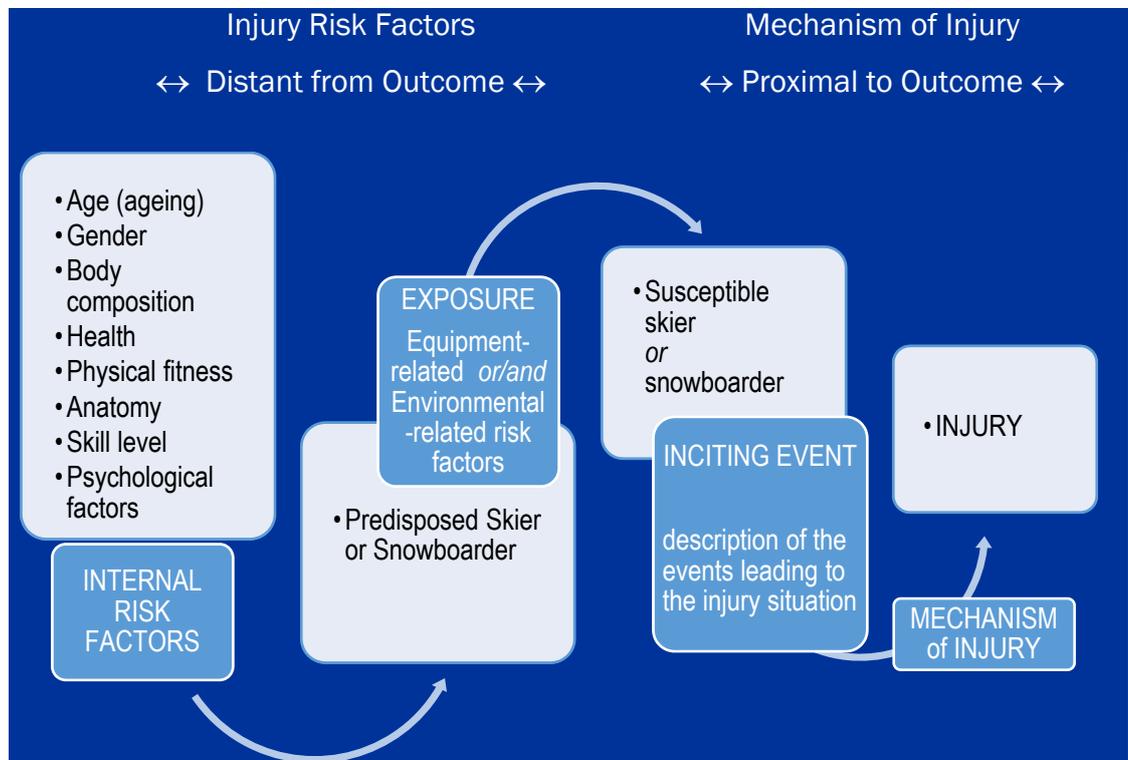


Figure 2.3: A comprehensive model for injury causation (adapted from Bahr and Krosshaug, 2005).

An example of the biomechanical detail elicited from this model was considering bone density in the ageing skier. As skiers remain active into their eighties the risk of hip fractures associated with osteoporosis, particularly in the female population was an important consideration (23). The physical changes of ageing were also cited as a causative factor in the higher numbers of knee injuries and tibial-plateau fractures in female skiers (24). Supporting continued physical activity in the older age group can reduce falls risk and improve wellbeing (25, 26). Education interventions for individuals based on joint and biomechanical information can improve performance (27). Snow sport instructions that considered postural patterns were found to improve balance and reduce the likelihood of falling. Measures such as the femoral intercondylar notch width at the knee joint assisted with understanding patella dislocation (28). Other anthropometrical measures provide alignment information.

Motivation and perception of risk also entered the causation foray in the Comprehensive Model for Injury causation (22, 29, 30). The challenge of measuring affective domains was clearly complex. To gain an in-depth understanding of the inciting event this model also promoted exploration of external factors. In snow sport the inter-relationship of the skier + ski and the snowboarder + snowboard with the snow (sports play situations) and protective equipment needs to be determined. The third section of this review addresses the snow surface and equipment interface.

Finch from “the Australian Collaboration for Research into Injury in Sport and its Prevention” raised concerns that injury prevention researchers were often caught in the inertia of describing the size and nature of the injury problem and did not progress to implementation (15). Her concerns promulgated the development in 2006 of the TRIPP framework , a mnemonic for a new injury prevention model “Translating Research into Injury Prevention Practice” where two stages were added to the four step van Mechelen model; namely Stage 4 and Stage 5 (see Figure 2.4). Prior to introducing preventative measures proposed interventions should be tested in ideal controlled conditions, with pilot studies or in focus groups (Stage 4). Once benefits have been discovered, the impact of an intervention on operations (ski areas) needs to be described (Stage 5). The addition of this stage provided opportunities to examine potential barriers that may undermine successful implementation. Researchers and external injury prevention specialists need to fully appreciate the increased operational complexity of introducing a new initiative at ski areas (31). For example, the additional hours of work required to implement research programmes and roll out injury prevention interventions on snow; the challenges of working with a seasonal mountain workforce with varied experience on snow; and the need for staff education at all levels of the organisation to help advance the safety culture.

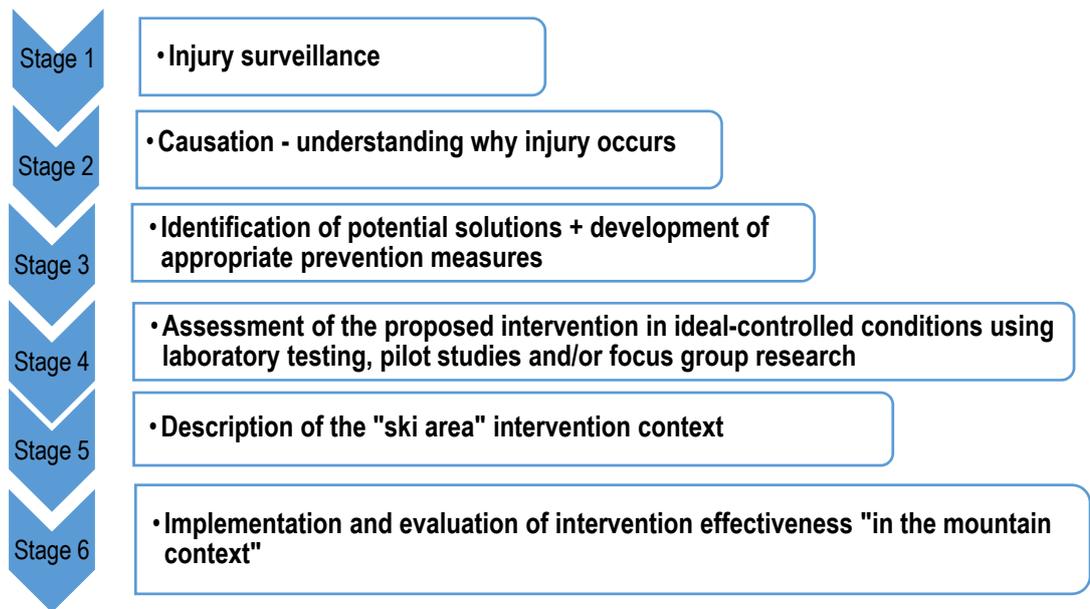


Figure 2.4: The TRIPP framework (adapted from Finch, 2006).

Over the following decade researchers grappled with the dilemma of re-injury and predisposition to injury. To ensure that the recursive nature of risk was considered Meuwisse and his Canadian colleagues expanded their original 1994 multifactorial model (21). A pictorial of the “Dynamic, Recursive Model of Aetiology in Sport Injury” (2007) provided in Figure 2.5 (32). An example of an equipment-related risk question that arose from this model was “would skiers with a previous knee or lower leg injury be able to perform the self-release manoeuvre and determine binding safety?”

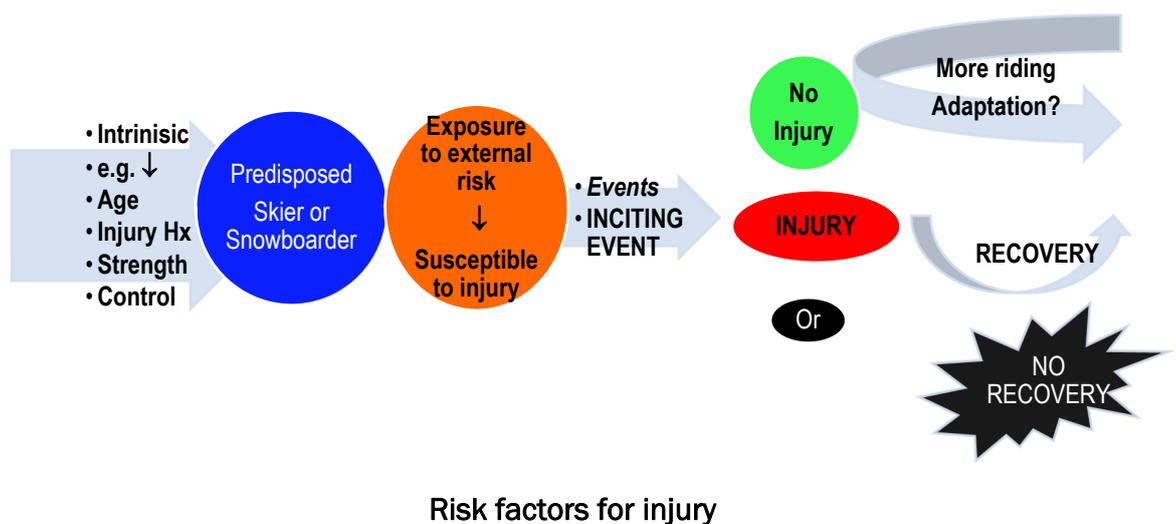


Figure 2.5: A dynamic, recursive model of aetiology in sport injury (adapted from Meeuwisse et al. 2007).

Van Tiggelen and colleagues at the Ghent University in Belgium in 2008 tackled processes that may interfere with potential preventative measures in a seven step model “the Sequence of Prevention of Overuse Injuries”(33). This model built on the work of van Mechelen and Finch by adding step 6 to look at compliance and risk-taking behaviours. When results were poor, researchers cycled back to proposing alternative preventive measures (TRIPP stage 3).

Application of behavioural and social science theoretical frameworks in injury prevention design across sports was limited, centring on increasing the uptake of personal protection equipment (34, 35). Risk-taking behaviours were most likely understood when the personality type of the skier and boarder were fully appreciated (36, 37). Understanding the push-the-limits, adventurous adrenaline junky (often young or young-at-heart) is essential as these personality types often have “follow-me charisma” which may expose others to risk or blunt the reach of injury prevention messages. Some injury prevention messages may need to be reworded to reach this target audience (38). Limiting stress during recovery is one example where a behavioural approach may help snow sports injured return to full activity and reduce the chance of re-injury (35). The gaps in literature on the psychosocial impact of skiing or snowboarding injury on the individual and their family were extensive.

Twentieth century changes in public policy in the United States of America used epidemiological research led by Dr William Haddon (5, 6, 39, 40). Notably, Haddon’s earliest manuscript (1962) centred on skiing injuries followed by a research career that contributed extensively to ameliorating road trauma. Considering injury as endemic allowed Haddon to use understandings of the inter-relationship between host, vector, and the spread of disease. Haddon created a matrix to assist decision makers allocate resources for injury prevention and inform strategic planning (see Table 2.1). The road trauma-related phases and factors detailed in the table below are clearly portable to snow sports. The most obvious application of the Haddon Matrix is in trail design, speed management in congested zones, and measures taken to prevent skiers and snowboarders colliding. Protective snow sports equipment such as helmets to mitigate forces of an on-snow crash another utilization. Considering the efficacy of protective equipment an important

step before inclusion in any pre-crash prevention initiatives (41). Skiing or boarding speeds of up to 82.2km/h with an average of 42.4km/h measured in male and female paediatric participants were in excess of the current ASTM snow sport helmet testing velocity of 23km/h (42). A risk of head accelerations above the concussion threshold also found over 40 kg. These findings raise important concerns about the currency of the snow sports helmet testing speed, regularity of revision of standards, and subsequently, the protective value of existing helmets. The speeds recorded demonstrate in the current era younger age snow sports participants are travelling as fast, or faster, than many of the vehicles involved in the road traffic crashes analysed by Haddon. A human factors approach cannot be one size fits all, the attitudes and behaviours of the population at risk will need to be accounted for.

Table 2.1: The Haddon matrix (adapted from Haddon, 1972).

Phase		Human	Vehicles	Environment
Pre-crash	Prevention	Information Attitudes Behaviours Enforcement	Road-worthiness Lighting Braking Handling Speed Management	Road design Speed limits Walkways
Crash	Mitigation	Use of restraint Disabling key if impaired by alcohol	Type of restraints Airbags Protection deformation design of vehicle body	Crash protection Road barriers Forgiving infrastructure
Post-crash	Sustaining life	EMS response	Access/egress Fire risk	Rescue facilities Congestion

The risk reduction tools used to analyse air accidents and medical errors (13) were also useful when considering systems risk at ski areas and off-hill rental shops'. Dr James Reason used a Swiss cheese analogy to explain accidents and to identify ways to stop such catastrophes happening again (see Figure 2.6). Each slice of the cheese represented successive layers of defence, barriers and safeguard.

When risks were not identified, holes in the cheese lined up and accidents occurred. Debate existed around the term “accident” as this term led to attributing the cause of the accident to an individual. With attribution of blame to an individual, organisations such as ski areas, outdoor groups supervising participation in mountain environments, hospitals and transport authorities were buffered from the need to improve systems (13, 43, 44). Reason refuted any blame culture that held individuals solely accountable for accidents and diluted organisations responsibility for harm. Reason promoted a cultural shift to collectively taking responsibility and collectively finding solutions. Snow safety rules, safety signs, and closing trails were three examples of system defences utilised by the ski industry to prevent individuals making poor decisions. Applying a systems risk lens to injury in skiing and snowboarding catalysed more questions; for example, are the present New Zealand safety rules and signs easily understood (38) and positioned appropriately?; once the safety message is heard or read will the skier or snowboarder act safely?; if not, why not?

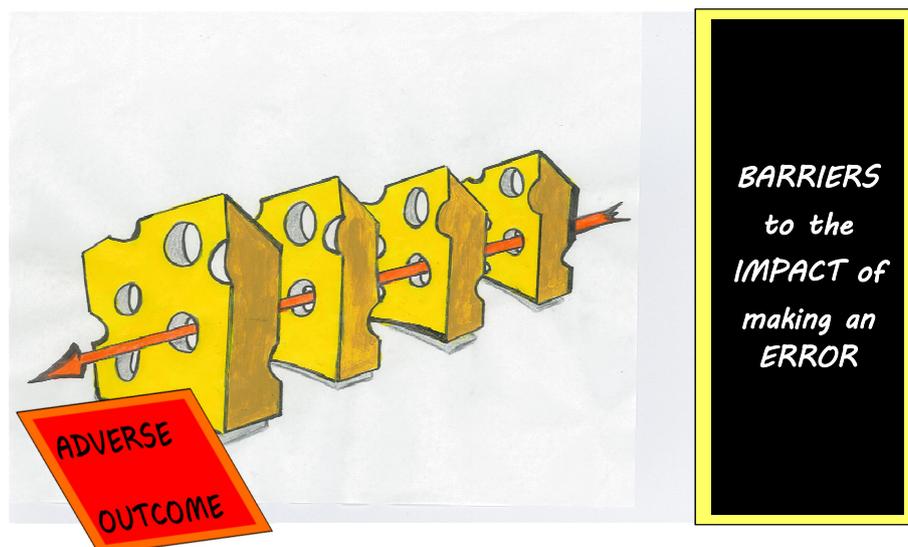


Figure 2.6: Human error model (adapted from Reason, 2000).

The New Zealand Accident Compensation Commission (ACC) cost-benefit injury model looked for a return on investment in sports injury prevention programs based on calculations of savings from injury reduction over the duration of the program (45). Government injury-prevention personnel commonly looked at health economics, describing severity in dollar terms rather than clinical terms. Finding

ACC related data that considered the psycho-social impact of snow sports injury on the life of a person proved difficult (18). Considering the whole person is integral to promoting recovery, the lack of psychosocial impact data was another glaring gap worthy of further research.

The Swiss Injury Prevention Council presented a dynamic holistic government perspective in the “Effect-orientated Prevention Cycle” (see Figure 2.7); significantly, this injury prevention model had been applied in snow sports (46). Multipliers were identified within mountain communities and the ski industry to extend the reach of the injury prevention interventions across the Swiss Alps.



Figure 2.7: Effect-orientated cycle (adapted from Bianchi et al, 2015).

This section highlighted that each group of researchers, risk reduction specialists or government agencies sought to unravel the complexity of the injury problem and the subsequent injury prevention solutions using models. The benefits of the sport specific models were that tangential curiosity was ring-fenced and each model drove focus. The Swiss Cheese (13) and the Haddon Matrix (5) ensured that people, equipment and environment risk factors were considered when working to reduce injury. A combination of approaches in reducing alpine skiing and snowboarding injuries was clearly of benefit.

## **Injurious events**

The cornerstone for determining the nature of the injury problem addressed in the first stage of the TRIPP framework is injury surveillance. Longitudinal population studies have informed snow sports injury prevention efforts from 1972 to present day. The Vermont research group, French Mediciens de Montagne Safety Network, and the Norwegian Ski Lift Association have led the way to our increased understanding of trends, patterns of injury, and causation of injurious events in snow sports (8, 9, 47-50). To enable effective comparison of these studies, members of the International Society of Skiing Safety agreed on research methods that should be employed worldwide (51). The reader needs to be cognizant of the limitations of these recommendations. Some jurisdictions only included injuries assessed and diagnosed by medical practitioners; whereas other areas only used ski patrol data. Number of injuries and patterns of injury slightly increased or decreased depending on the type of data entered into incident database. In Canada there were concerns that ski patrol databases had increased the number of inaccurate diagnoses; these doubts were refuted (52). In New Zealand (NZ) ski patrol data were collected by medical practitioners, ski patrollers and other health professionals that worked in mountain clinics (53). No previous in-depth analysis of the reliability of NZ ski patrol data was found. Visitation numbers were determined using ski area ticket sales (51). The limitations of ticket sales were that gender and skiing or snowboarding participation, were not necessarily recorded by all ski areas. Data collection omissions negate opportunities to determine injury trends by gender or specific snow sport. Population at risk calculations also needed to account for season-pass average days skiing or snowboarding. Depending on the monitoring systems or survey data gathered by ski areas on season-pass holder participation these calculations potentially were only “a best guess”. Another challenge for determining the size of the skiing and snowboarding population is that some season pass holders alternate between skiing and snowboarding depending on snow conditions or their friend’s preference so cannot be recorded for a single activity. Introduction of electronic monitoring at lift-lines may improve determination of the population at risk of injury.

Where researchers in New Zealand had no access to ski area visitation numbers, census data were used (54, 55). New Zealand census data calculations were likely to be inaccurate as increases or decreases in participation cannot be

determined. Census data analysis cannot account for the impact of closed ski area days from fluctuations in the weather, snow-pack cover or stability. These statistics also cannot account for days when the surface was icy, conditions that may limit beginner skier/boarder participation.

A brief historical perspective on snow sports is required to fully understand injurious events and work through stage 1 – injury surveillance and stage 2 of TRIPP - causation. Alpine skiing was a form of transport over snow for over 5 millennia and evolved into a recreational and competitive sport in the 19<sup>th</sup> century (56). Snowboarding a relatively new sport was invented late last century and popularised at the 1998 Winter Olympics in Nagano, Japan (57). Around the time of the Nagano competitions researchers started reporting data as skier/boarder days; however, to-date skier days are often used to describe the prevalence of injury in both sports. From 1974 to 1988 injury rates ranged from 0.8 in Japan to 9.1 per 1000 skier days in the USA (53). In the USA the 2010 weighted skiing incident rate was 2.5 per 1000 visits declining from 3.1 in 1980, 2.7 in 1990, and 2.6 in 2000 (47). Lamont examined NZ ski patrol incident reports at one South Island ski area in 1988 and reported an injury rate of 4.7 per 1000 skier days (53). With support of the NZ Mountain Safety Council data collection forms were created for use at NZ ski areas based on the Orthopaedic International Classification of Diseases – 9<sup>th</sup> Clinically Modified edition were used at five ski areas in 1989 and seven in 1990. (7). Injuries declined, 4.5 to 3.3 per 1000 skier days, with the decline attributed to a bumper snow season in 1990. ACC notably did not have a sport-specific database to assist in description of the alpine skiing and snowboarding injury problem. High injury rates in epidemiological studies are clearly of concern, as are numbers of severe injuries.

The stratified ten year interval study of National Ski Patrol incident reports in the USA (47) found skiers had a higher incidence of knee injuries and conversely snowboarders had a higher incidence of wrist injuries (see Figure 2.8).

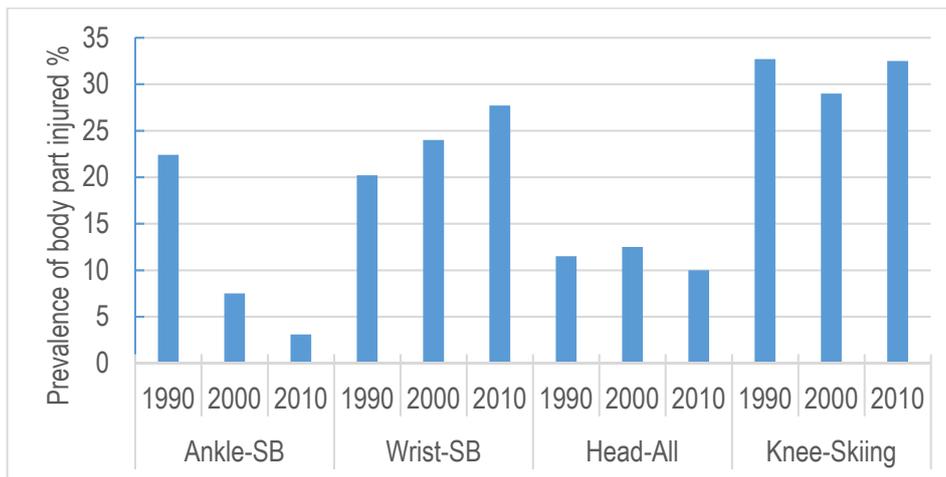


Figure 2.8: Injury prevalence by snow sport (adapted from Shealy et al, 2015).

Ankle injuries in snowboarding declined significantly over two decades. Despite the increased use of protective helmets (0 - 61%), head injury as a percentage of all injuries in both snow sports was relatively static. These USA injury trends mirrored injury trends reported in France, Norway and Scotland (9, 50, 58, 59). Of the total downhill skiing injuries 12.5% were knee ACL injuries compared to 0.6% of snowboarding injuries (48, 49). The longitudinal studies undertaken by the Vermont Safety Research group (8, 60, 61) at Sugarbush ski area provided further evidence that injury trends did not differ significantly across the world.

In New Zealand, local data on injury trends by body part was limited. Cardrona Ski Area (South Island) in 1988 reported that knee injuries occurred in 27% of skiers vs. 14% tibia fractures (53). At Whakapapa ski area, knee injuries in skiing were 14% vs. 3% tibia fractures. Forearm fractures were 3% of all skiing injuries and only reported at Whakapapa. Southern Lakes Region (New Zealand) ski area hospital admissions in the period 1991 – 2002 found 26% were spinal injuries (18 snowboarders and 7 skiers) with one fatality from a burst C5 fracture (62). The small sample size limited any conclusion on risk factors. Ski-lift injuries and hospital discharge data for the same catchment (Otago) found that lift-related injuries were rare (54, 55). From a retrospective case series of 171 wrist injured snowboarders aged 14 – 17 years snowboarding at Turoa (North Island ski area) it was found that 70% had wrist fractures, most were male, beginners, and only 30 wore wrist protectors. The researchers could not determine whether wrist guards were part of the injury problem or were protective and recommended more research.

## The Knee

Knee injuries that occurred skiing were the most common injury. The increased prevalence of knee injuries (194%) was attributed to changes in ski design (56, 63-69). With the advent of the carving ski, injury trends shifted significantly from minor knee sprains that predominantly involved the medial collateral ligament (MCL) to serious Grade III Anterior Cruciate Ligament (ACL) injuries. Grade I (no laxity) and grade II (laxity) knee injuries remained constant (11, 70). The increased incidence of Grade III injuries that created an unstable knee was of major concern. Most grade III tears involved the ACL not the posterior cruciate ligament (71). Many ACL injuries included rupture of the medial collateral ligament.

Female skiers injured the knee more often than their male counterparts did. Anatomical differences were often cited as reasons for the increased ACL injury in females in skiing and other sports such as netball and handball (72, 73). Gender differences included alignment of the lower limb; quadriceps-angle and dimensions of the femoral intercondylar notch; laxity of the knee joint; and, reduced endurance levels (72, 74, 75). Female skiers were 2 to 3 times more likely to injure the knee than male skiers (75-77). Leg muscles appeared to fatigue more easily in females during anaerobic exercise due to poor elimination of lactic acid. For females in the pre-ovulatory phase, the odds ratio (OR 2.38) of being injured was significantly higher than in other stages of the menstrual cycle (78). Oestrogen levels appeared to change the collagen remodelling process leading to reduction of ligament strength in women.

Researchers using computerised laboratory experiments identified 17 critical loads that could lead to knee ligament injuries (see Table 2.2). These laboratory studies offered a controlled environment to examine causation. Video footage of skiing accidents and 3D modelling provided further evidence of critical loads (79). Case control studies were reliant on the injured skier's recall of the mechanism. Given that recall in an accident could be clouded by pain, fear, other distracting injuries or disorientation, retrospective data on injury mechanisms may not necessarily be accurate. Frequency data on the various ACL mechanisms in case control studies were limited. In valgus rotation (load 2c) when falling forward, 20% of falls resulted in medial collateral ligament (MCL) tears and anterior cruciate

ligament (ACL) rupture (80). Some researchers postulated that the phantom foot mechanism (load 3e) was the most common cause of ACL injuries (81).

Table 2.2: Critical loads during skiing that lead to knee ligament injury (adapted from Freudiger & Frederich, 2000).

<b>CRITICAL LOADS</b>	
<b>FLEXION</b>	
1a	Flexion with anterior-tibial load Landing on the ski tail Backward fall Raising from or avoiding backward lean by quadriceps-pull
1b	Flexion with enforced anterior-tibial translation Transition of sliding upper body from uphill to downhill side
1c	Hyperflexion
2a	External rotation in hyperextension or extension Upper body rotates instead of skis
2b	External rotation + anterior-directed translation
<b>MOVING DIRECTION FORWARD</b>	
2c	External rotation + valgus Ski tip turns outwards Body centre of gravity clearly in front of the binding
2d	External rotation + valgus in flexion Body centre of gravity clearly in front of the binding
2e	External rotation + valgus + anterior-directed translation Body centre of gravity clearly in front of the binding
2d	External rotation + varus + anterior-directed translation Body centre of gravity clearly behind the binding
2e	Internal rotation in hyperextension or extension Upper body rotates in flexion
3b	Internal rotation in flexion
3c	Internal rotation + varus Ski tip turns inwards Body centre of gravity clearly in front of the binding
3d	Internal rotation + varus in flexion Body centre of gravity clearly in front of the binding
<b>MOVING DIRECTION BACKWARD</b>	
3e	Internal rotation + valgus in flexion (hip-below-knee) "Phantom Feet" Body centre of gravity clearly behind the binding
3f	Internal rotation + valgus + anterior-directed translation Body centre of gravity clearly behind the binding
4a	Hyperextension or extension
4b	Hyperextension + internal rotation + varus

To be exposed to the phantom foot mechanism the skier was facing down the slope, became unbalanced then produced deep flexion or/and an anterior drawer effect (lower leg pulled forward). The skier's weight was then placed on the internal edge of the downhill ski and the unweighted uphill ski produced a sudden internally rotated lever effect (phantom foot) when the skier was off balance to the rear. The levering effect resulted in knee injury. Laporte et al presented a counter argument to the phantom foot load being the primary ACL injury mechanism as 60% of knee injuries were found to have occurred in forward falls (48, 82, 83). Forward falls generated forces that could lead to release from the ski binding. Standard dual-directional ski-bindings cannot provide protection and release in unweighted backward positions; however, in forward falls a ski-binding that is correctly set-up may offer protection to the knee (84). A decrease of grade I and grade II medial sprains was found with improved ski-binding function (82).

Correct binding set-up and skier education were the primary prevention solutions that were promoted by the Vermont group that discovered the phantom foot mechanism (70, 85). An education program that taught skiers to go with the fall, stay down, and not try to recover was successful in reducing knee injuries in USA ski instructors. The attempt to recover was purported to increase the lever effect of the phantom foot. Norwegian and Vermont Orthopaedic surgeons supported undertaking daily self-release manoeuvres before skiing. This manoeuvre supposedly established that the ski binding was functional and set-up appropriately (86-88). Torque testing to ensure safe set-up of rental ski-binding-boot systems calibrated to ISO-11088 standard was also promoted as a prevention solution for knee and lower leg injuries (89-92). The Vermont group alongside the education intervention designed a torque wrench for equipment testing.

Based on case control data, Medicine de Montagne Safety Network advocated for lowering of the international ski-binding release settings (92, 93). To make changes to the International Standards Organisation (ISO) adjustment release table consensus was needed; however, gaining agreement between other researchers, medical insurers and manufacturers was not successful (94). To circumvent the lengthy timeframe required for consensus decision-making Laporte et al developed the AFNOR, Alpine ski bindings Setup fixations - Recommendations on adjustment release levels (83, 94). This standard recommends reduced ski

binding adjustment values for at risk groups: women by 15%; men below 49 kg a reduction of 15%; men 49 – 57 kg a reduction of 5%; and men over 57 kg no change from the standard ISO tables (92). Scotland and Andorra have adopted the AFNOR FDS 52–748 standard. No detail has been published on the set-up standards being used by New Zealand ski rental and retail shops.

### The Head

Head injury was a broad term used to describe soft tissue injuries of the head (grazes, lacerations and bruises), concussion, skull fracture, traumatic brain injury (TBI) and different cerebral bleeds (47). Head injuries in Switzerland were 11 to 12.5% of all snow sports injuries (95, 96). Children were twice as likely to sustain a head injury as any other age group (95-98). Concussion rates were estimated to be 2.5% for skiing and 4.5% for snowboarding (99). Head injury was more likely to occur in males than females (OR 1.43), and happen in a collision rather than a fall (OR 4.15) (100, 101). Importantly, head injuries were not equal in terms of morbidity (102-106). In a technical report on snow sports head injuries written for the Coronial Services of New Zealand in 2011 (103) preliminary analysis of New Zealand ski patrol data (2005-2008) indicated that head injuries were 11.7% of all injuries and 4.9% of those injured had concussion. To determine the protective value of the helmet it was necessary to know the percentage of the population protected by the helmet. The number of New Zealand skiers and snowboarders with bare-heads vs. protective helmet wear for the period 2005 to 2008 was unknown. In France in 2008, 90% of children 11 years and under wore helmets (95). For 2009, Switzerland reported 65% of skiers and snowboarders wore helmets with a 90% reach for children under 17 years of age. Regardless of helmets, snowboarders using terrain parks were more likely to suffer a head injury with loss of consciousness than skiers were.

Snow sport helmet standards were determined from a battery of impact testing (42, 107, 108). The protection value of helmets designed specifically for use when skiing or snowboarding was first determined in laboratory simulations (TRIPP stage 4). These simulations measured linear acceleration in a 2.0 m helmet drop onto a steel surface to not more than 300 g with a speed to impact of 27.7 km/h (109). Further impact tests were undertaken on snow on an intermediate trail with an anthropomorphic snowboarder testing device in a manner replicating an average

speed of 43.5 km/h. Falls in soft snow with or without a helmet did not produce the g-loads likely to cause head injury as the energy was dissipated in the snow. In contrast, when the snow surface was icy significant transfer of energy occurred through deformation of the helmet. Helmet use in these hard snow surface conditions was estimated to reduce the probability of a skull fracture and severe brain injury from approximately 80% to 20% respectively. In simulations of a snowboarder, colliding with a fixed object at 30 km/h the helmet reduced the head accelerations by more than a factor of two. Over 300 g the probability of a skull fracture and severe brain injury when wearing a helmet remained at 99.9%. Proportionally heads are larger and heavier in children. Paediatric simulation impact testing were based on an average child skier's speed on an intermediate slope of 18.7 km/h (110-112); wearing a helmet reduced the probability of a traumatic brain injury in the paediatric population by 0.2% or less. Results from laboratory and field tests indicated that helmets were not a complete panacea for head injury. Helmets reduced abrasions, lacerations, and mild concussion but there was no evidence that the helmets reduced traumatic brain injury-related deaths (99, 113, 114). The effect of a mild concussion cannot be dismissed as "nothing to worry about" as an individual's ability to concentrate and perform daily tasks maybe limited for months or years following this type of trauma (18, 115, 116).

Most countries bolstered voluntary use of protective helmets by providing education. In jurisdictions with the mandatory use of a helmet the catalyst for these rule changes were high profile deaths rather than research findings (103, 117). The actor, Natasha Richardson died of an extradural haematoma after skiing at an Intrawest ski area in Quebec; she was not wearing a helmet. The high profile manslaughter verdict of a German politician led to the creation of the Austrian mandatory helmet rule. Dieter Althaus was wearing a helmet skiing but he did not comply with the slope give way rules and was involved in a fatal collision with a female adult skier who was not wearing a helmet. Mandatory helmet wear for teenagers and children was established in Italy and Croatia in 2005 (14 years and under); at all nine North American Intrawest ski resorts for children and teenagers in 2009 (age not specified); and in Austria, helmet use became compulsory in 2010 for children aged less than 16 years.

The limitations of the head injury studies were that snow surface conditions and risk-taking behaviour generally were not explored. Understanding risk factors may provide an explanation for the higher odds ratios of head injury for males. As indicated in the “Comprehensive Model for Injury Causation”(22) analysis of the environmental factors associated with collision would inform interventions. This section has identified that there are significant gaps in the literature; namely no current New Zealand injury trend data and no data on the numbers of New Zealand skiers and snowboarders wearing helmets.

### **Snow as a playing surface**

The previous section focused on the magnitude of the injury problem, introduced the issue of equipment-related risk in incorrect ski-binding set up and discussed protective value of snow sport helmets. This section seeks to increase understanding of the interplay between equipment and the snow to inform analysis of the external factors involved in injury (22). Mountains are a recreational environment with a playing surface largely crafted by the natural elements. Injuries in epidemiological studies were predominantly attributed to falls on the snow, colliding with another skier, snowboarder, chairlift tower or a tree. With no trees above the New Zealand snow line, this environmental risk factor could be excluded.

Increasing understanding of what was happening at a microscopic level in the snow-pack illuminated the risks associated with this particular playing surface (118, 119). The snow-pack is dynamic; “snow is not just an amorphous mass. Soft loose layers and icy crusts often exist below the surface” (p 37) (120). Bonding of snow crystals below the surface determines the stability of the snow-pack and the risk of avalanche (119-121). Snow is created when moist air cools, mostly in temperatures from zero to minus 20 degrees Celsius. Lower temperatures of below minus 20 degrees generally see the air dry out. Snow is formed when hexagonal prisms nucleate around a dust particle, dendrites that look like microscopic arms grow from the corners of the hexagon to form complex crystals. The symmetry of each snow crystal is unique and the growth of the dendrites of snowflakes differs with changes in temperature. Temperature and melt cycles change the morphology of snow, which in turn affects crystal bonding. When new snow loads on the slopes and a skier or snowboarder makes turns on snow that has weakly bonded ice layers,

being caught in an avalanche is added to the injury risk. Snow-pack data can inform playing surface and surface stability injury prevention messages.

The surface landed on may range from a soft forgiving powder to hard icy concrete-like surface where the force is taken by the body rather than dissipated in the snow-pack. In video analysis of world cup skiers, aggressive machine made water prepared or injected snow conditions generated larger forces than natural snow when carving at speed (79). Machine made snow was dry, hard and increased the risk of catching an edge and falling. Machine made snow has different morphology to natural snow as water droplets freeze on the outside before freezing on the inside (122). The spherical grain shaped snow is sometimes hollow, and the NZ maritime climate may increase the water content, adding to bonding issues. Any inconsistencies in the machine-made snow playing surface, could affect glide and increase the risk of falls. Of concern is that machine made snow is often used on lower mountain easy terrain slopes frequented by learner skiers and snowboarders that are less able to adapt to changes in the playing surface. There were no studies on machine made snow in the New Zealand mountain environment.

Sliding over snow maybe more complicated than ice as snow has a variety of conditions. Snow may consist of angular dendrites that increase the solid-to-solid component of friction. The two types of friction described between skis or a snowboard and the snow are dry friction and wet friction (118, 119). Pre-melt layer formation in wet friction potentially is accelerated by humidity, rising air temperature, changes in snow temperature, and solar radiation. Dry friction occurs when the base of the ski or snowboard generates heat and a melt cycle. A lubricating water layer created between the equipment base and the snow reduces friction between the surface of the ski or snowboard and the snow. Determining the thickness of the lubricating water formed in dry friction is problematic, as pressure distribution from the athlete on the equipment base will vary. Federolf et al cited (118) the broad range of scientific studies published between 1939 – 2007 that support the hypothesis of a water film that acts as a lubricating layer reducing friction. As more water is produced shearing of snow surface layers and capillary infiltration of water in the snow pack occurs. Kinetic friction equals dry friction and/or wet friction + capillary drag + displaced snow resistance + compression of snow (119). Capillary drag occurs when the ski adheres to the snow in a suction-

like effect between the surface of the equipment and the snow. In some conditions, the snow surface will grip the base of the ski or snowboard and compromise balance. Bases of alpine skis and snowboards are made of polyethylene. Extruded, sintered or infused graphite are added to the polyethylene to create a porous surface that absorbs wax and provides a low friction surface. Turning precision and edge protection is provided by steel alloy. The properties of the alpine ski or snowboard base and edges work with, or at odds with the kinetic friction of snow (118). Giant slalom skis with an increased side-cut radius were found to decrease kinetic energy by 5.6% and reduce the risk of knee injury (123). Analysis of the benefits of changing the ski edge to-date has only been assessed in ski racing. Gaining further understanding of ski base and edge kinetics in the recreational skiing population is needed (124).

Friction changes with: the roughness of the snow, grain size and crystal shape, bonded strength of the snow, water content in the snow, heat generation by shearing water as the ski moves across the snow, water removal by shearing, and changing temperatures of the surface of the snow. Conditions that impede glide and possibly make turning difficult will influence equipment performance. When the ski or snowboard does not move as predicted on the snow the position the person on the equipment may assume may increase the risk of an injurious event. The flexibility, size and weight of the ski or the snowboard (and the athlete) are important factors in determining the proportion of the equipment that is in contact with the snow and the co-efficient of friction (COF). It stands to reason, the larger surface area of the snowboard kinetic friction values would be higher when snowboarding; however, no studies could quantify this assumption.

Speed and load on the snow contribute to COF. Waxes were developed to improve glide by making the ski or snowboard base hydrophobic (125). Alpine waxes are composed of alkaline paraffin with additives such as graphite, polyfluoroethylen, silicone, fluorocarbons, or molybdenum disulphide (125). The combination of additives ensures that the wax is either hard for use in colder conditions, or soft and suited to warm wet conditions. The correct choice of wax is important in providing the winning edge for the ski racer and the safer more enjoyable glide for all who recreate on alpine skis, Nordic cross country skis or snowboards. Alpine wax needs to be fit for purpose and create a water repellent surface that lowers the coefficient

of kinetic friction (COF) (126). Beginners and intermediate skiers and boarders identified as groups that could benefit from wax information. Routines around reapplication of wax on rental equipment were unknown. There also was no current wax data that could be used in injury prevention messages.

An understanding of the construction of the snowboard or the ski and the capacity of equipment to respond to both the snow surface and the athlete informs understanding of the injurious moments that may occur more often with particular types of equipment. Snowboards are constructed mostly of wood cores that limit the equipment weight and provide flexibility (127). Honeycomb cores used in the expensive end of the snowboard market, and foam cores at the cheaper end. The core wrap thickness dictates the strength of the snowboard. The construction of the core also dictates the energy storage properties of the snowboard. The snowboarder adjusts position to negotiate the slope. With a twin-tip board, the snowboarder can place pressure at either end of the snowboard on the fall line of the slope. The snowboard non-release boot binding system keeps the boarder with the board resulting in less knee injuries than skiers (7% versus 32.5%) (47).

The challenge for ski designers wanting to improve performance and reduce injury risk has been to construct structures that are highly deformable and easy to guide on the slope in straight manoeuvres and turns. Traditionally alpine skis were wooden, straight and heavy, with the length of the ski divided into three functional parts: the tip, waist, and tail. Artisan craftsmen improved the camber of the wooden ski in the 20th century and from the 1950's alternative materials came to market (128). Materials such as laminated wood, laminated metal, rolled stainless steel, kevlar, carbon-fibre, plastic foam, fiberglass, and glue between layers enhanced strength. The various combinations of these new materials made skis viscoelastic and ensured dynamic movement across the slope. The torsion box and cap construction created additional strength by wrapping either metal or fiberglass around a wooden core. Camber, ski-edge height, width, length and the geometric characteristics of the side-cut determined the kinematic behaviours of the ski on the snow (129). The wider the ski the better ability to travel through powder snow. However, the wider ski may have more drag forces when compared to the narrow ski. High torsional rigidity dampened vibrations and improved grip on the snow surface at high speed. In the soft ski the opposite effect was seen where

the skier could easily initiate short skidded turns (128). The carving ski was a revolutionary enhancement that has increased the appeal of the sport from 1993 to present day. Old ski designs did not have all of the ski edge on the snow surface at any given time requiring additional length to ensure speed (129). The side-cut construction of the carver allowed for increased edge contact with the snow, less vibration, and fast snappy turns in a reduced radius. The self-steering behaviour of the carving ski was observed to place skiers in a different trajectory than planned and increase the risk of knee injuries (64, 65). The changes to ski construction increased the lever arm effect and the surface friction. Skiers on carving skis needed a different skiing technique that centred balance. When the skier was in the correct position on the ski, the edging behaviour was improved. Despite advances in equipment design and construction, carving skis continue to be associated with the increased incidence of knee injury, specifically rupture of the ACL (48, 124).

To understand skiing injury mechanisms of the knee and lower leg an understanding of the ski-binding-boot system is also essential. The conventional dual-directional ski binding is constructed using levers and springs, has an AFD plate or rollers (antifriction device) and releases in twist (Mz) and forward lean (My) directions. The ski binding indicator scale indicates the release torque; colloquially the release value is referred to as, the DIN (Deutsche Industrial Norm), after the German standards body that undertook some of the initial ski equipment standards work.

A DIN of 6.0 equals 65 Newton metres (Nm) of torque in Mz and 261 Nm in My with a boot sole length of 327 mm. The skier will release from the ski binding when a load is created above these torques. In the last decade integrated ski-binding-boot systems have come to market with railroad tracking between the toe-piece and heel. Integrated systems work well in rental shops, as it is easy for ski technicians to fit the binding to different boot sole lengths. Ski racers used lifters when mounting bindings to increase the distance between the foot and snow; however, the increased distance from the playing surface was found to increase the risk of injury (130). The affect of tracks between the toe and heelpiece could be similar to lifters, make the ski stiffer through the waist, and affect performance.

This section has highlighted the complexity of snow, the friction that the equipment has to overcome to move, and the snow sports equipment design features that enhance movement on the playing surface. The published research does not necessarily keep pace with equipment released to the market. Teams on the World-cup circuit with the winning wax formula are not likely to be benevolent with information. Manufacturers that invest in research appear to keep commercial advantages by not sharing data (131). There were no studies on the effect of the recreational integrated toe and heelpiece system or wax.

## **2.4 Summary**

The tripartite division of topics: 1) sports injury prevention, and risk reduction models; 2) injurious events (focused on the knee and the head); and, 3) snow as a playing surface have identified knowledge gaps that inform the chapters that follow. No single approach to an injury prevention PhD was found in the injury prevention and risk reduction models that were described. Practical reasoning assisted decisions on which models to apply. The TRIPP framework (15) addressed the implementation short falls found in the van Mechelen model (17). No data found on current injury trends in alpine skiing and snowboarding in NZ created the starting point. The injury surveillance required in stage one of TRIPP would determine the size and nature of the injury problem. Importantly, using all six stages of TRIPP would ensure that the thesis moved past describing the injury problem to find real-world solutions.

A biomechanical approach was also needed to understand the risk factors. Apart from the Coroner's reports, there was no overall analysis of deaths at New Zealand ski areas. The proportion of the skiing and snowboarding population wearing a helmet was not known, limiting determination of the reduction in head injuries by using helmet protection. In terms of equipment-related risk, New Zealand ski-binding adjustment practices were not known. The performance and risk factors of the new rail system in rental bindings also had not been explored. Current wax information and testing data in different snow conditions was missing. There were no studies on ACL awareness education in recreational skiers and limited data on the successful protection of ski area staff from knee injuries using the Vermont education intervention. There was also limited data on the melt factor and bonding

of machine made snow in comparison with other snow conditions that could increase or decrease playing surface risk. Along with further epidemiological and biomechanical evidence, risk reduction criteria were needed to draw together the solutions for injuries in alpine skiing and snowboarding. Both Haddon and Reason add to the schemata of the thesis going forward.

## CHAPTER 3 – THE INJURY PROBLEM

### Prelude

Population-based injury surveillance promulgates both questions on answers already concluded and provides volumes of data for resolving unanswered questions. From review of the literature in Chapter 2, there were clear epidemiological gaps. New Zealand incident data collected at ski areas were analysed in 1993 and there were no snow-sports injury studies examining Accident Compensation Commission personal claimant data. This injury surveillance chapter compares both database and determines the current size and nature of snow sports injuries in New Zealand (TRIPP stage 1).

## **Part 1: The utility of two national injury databases to evaluate snow-sports injuries in New Zealand**

### **3.1.1 Introduction**

The development of the New Zealand snow sports injury-prevention strategy (132) provided the impetus to increase understanding of skiing and snowboarding injuries and apply discoveries made. Traditionally, the magnitude of the injury problem in alpine skiing and snowboarding was solely determined for Ski Areas Association New Zealand (SAANZ) using the NID database. NID analysis provided only one part of the picture, injured people that were assessed and treated at all commercial ski areas. To determine the true magnitude of the injury problem, the proportion and type of injuries that bypass mountain clinics and then seek treatment off the mountain, needed to be determined. The ACC database provided all personal injury claims for snow sports; comparison of both the NID and ACC would provide a complete picture.

### **3.1.2 Aims**

The primary aim of this study was to quantify the magnitude and nature of the injury problem in alpine skiing and snowboarding in New Zealand. The secondary aims were to determine the utility of two snow-sports injury databases and inform the development of a national injury-prevention strategy.

### **3.1.3 Methods**

The NID incident reporting form was revised by the primary researcher and a SAANZ working group in the summer of 2010 prior to commencing NID data collection (see, Appendix II). Data collected at all ski areas was modified and expanded to include: resident or non-resident; free text space for description of the incident; fall, jump/landed, or slide; type of lift (chairlift, T-bar, platter, rope tow, carpet lift, fixed grip tow); equipment ownership (self-owned, borrowed, rented on-hill, rented off-hill); equipment maintenance (binding calibration this season, > 1 season, or never) and ski-binding release settings; skier height and weight; ski-binding release, no release, or premature release; and, terrain-park detail (box, jump or rail). Activity, collision factors, visibility, snow conditions, protective equipment, and the injury

code data points were retained unchanged. Ethics approval was gained from the Auckland University of Technology ethics committee (#14146) and the ACC ethics committee (#258). Descriptive epidemiological analyses and comparisons were made of ACC personal injury claimant data from the legislated government no-fault insurance scheme and the NID for incidents treated at all commercial ski areas 1 June to 31 October in 2010 and 2011. SAANZ provided population numbers for each season using ticket sales and season pass records. The ACC diagnosis, read code and read code description data were used to group ACC data into the condition categories used in the NID. Analysis of the comprehensive cost details in the ACC data was not undertaken. Medical condition categories in the NID were not included. Both data sets were evaluated for completeness by undertaking checks of blank fields and missing codes.

Proportions of injuries and injury risk were analysed using Poisson or logistic regression. Analysis was performed with the Statistical Analysis System (SAS). Injury rates per 1000 skier days were determined using SAANZ population data. A factor of 0.82 was applied to ACC injury counts to remove injuries that occurred outside commercial ski areas and thereby, allow comparison with NID counts. The p value for the difference of the rates was derived by assuming the normal approximation for the sampling distribution of the two proportions and by assuming (conservatively) the independence of the two proportions. The ratio of the proportions was assumed to have a log-normal sampling distribution, and the confidence limits for the ratio were derived from the p value using a spread sheet (133). The magnitude-based inference to assess the uncertainty in the outcomes was also calculated in this spreadsheet. Proportion ratios of 0.90 and the inverse 1.11 were assumed to be the smallest clinically important ratios.

### **3.1.4 Results**

The ACC database provided body part injured and diagnoses on 24,793 incident claims. The data required considerable checking, filtering and manipulation to resolve inconsistencies in recording the nature and location of injuries. Missing data were found for <2% of ACC cases; these blanks did not impact determination of a diagnosis. ACC incorrectly attributed <0.01% of snow-sports injuries to water-skiing, jet skiing or wakeboarding. Text written by the injured skiers or snowboarders

(claimants) describing the mechanism of injury was not thematically analysed, as apart from “fall”, there was no consistency in terms.

The NID provided comprehensive descriptive data on 7,851 incidents. Ski-binding release, non-release and ski equipment servicing data were collected only in skiing knee and lower-leg injuries. Missing data were found for <1% of NID cases; these blanks did not affect determination of a diagnosis. There were no differences in NID incident reporting practices at small ski areas staffed solely by ski patrollers when compared to large ski areas staffed by doctors, nurses, radiographers and ski patrollers. Coding of injury severity was not consistent in the NID. For example, fractures that occurred in the same part of the body were either coded status 3 moderate or status 4 minor. Status codes were also problematic in three cases where minor injuries were incorrectly recorded at one ski area as deceased. A ski area manager corroborated the coding error. Mortality data from the Coronial Services of New Zealand confirmed the dates, times and causes of three ski area fatalities (2 skiers, 1 snowboarder). Two of three of these fatalities were recorded as status 1 critical, and the third fatality was not recorded.

The overall injury rate for the combined winter seasons 2010 and 2011 was 8.8 per 1000 skier/boarder days (ACC) and 3.2 per 1000 skier/boarder days (NID). Sprains accounted for the biggest difference in injury rate between the ACC and the NID (5.3 and 1.3 respectively). Figure 3.1 provides a graphic of the differences in all injury categories.

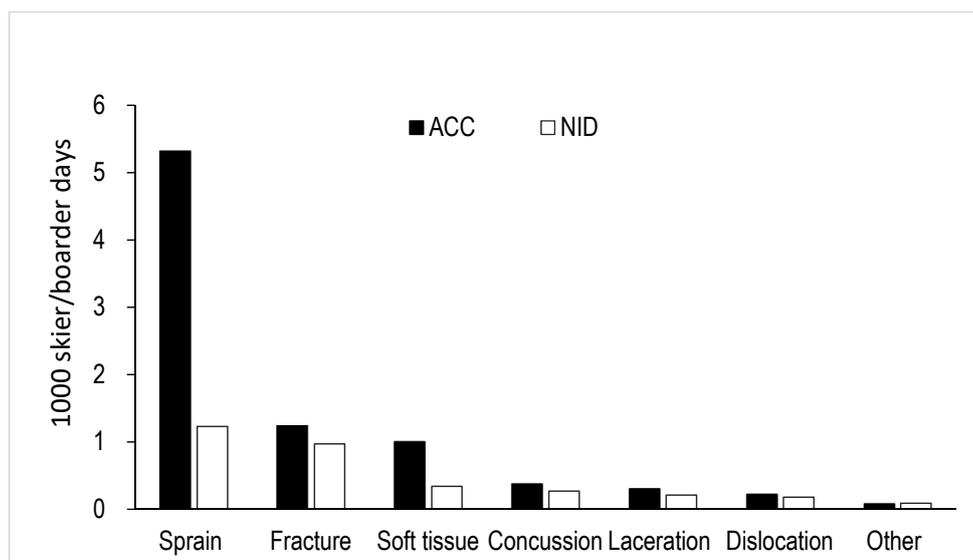


Figure 3.1: ACC NID comparison of injury type per 1000 skier/boarder days.

In comparing the injury counts per 1000 skier/boarder days for the ACC and NID shown in Figure 1, sprains were 5.3 vs. 1.2 (ratio 4.3, 99% confidence interval, confidence interval 4.2-4.5); fractures 1.2 vs. 1.0 (ratio 1.28, 1.19-1.36); soft tissue 1.0 vs. 0.34 (ratio 2.9, 2.7-3.2); concussion 0.38 vs. 0.27 (ratio 1.4, 1.3-1.6); lacerations 0.31 vs. 0.21 (ratio 1.5, 1.3-1.7); dislocation 0.23 vs. 0.18 (ratio 1.3, 1.1-1.5); and other injuries (burns, nerve injuries, foreign bodies, dental) 0.09 vs. 0.09 (ratio 1.0, 0.8-1.3). Internal injuries were extremely rare: 8 ACC cases and 15 NID cases respectively.

The approximate proportion of the population active in each snow sport was: 61% skiers, 32 % snowboarders, 7% both ski and snowboard. Skiers suffered more sprains than snowboarders (ACC 68% vs. 54%; NID 48% vs. 28%), less fractures (ACC 10% vs. 21%; NID 21% vs. 38%), and similar proportions of concussion (ACC 4% vs. 5%; NID 8% vs. 9%). The proportions of other injury categories were similar for skiers and snowboarders. Similar agreement between the ACC and the NID were found for body part injured. For example, sprains commonly involved the knee in skiers vs. snowboarders (ACC 33% vs. 15%, NID 54% vs. 21%) whereas snowboarders had more wrist fractures than skiers (ACC 54% vs. 24%, NID 57% vs. 22%). Sustaining a fracture of the lower leg remained the domain of skiers rather than snowboarders (ACC 16% vs. 3%, NID 16% vs. 2%).

### **3.1.5 Discussion**

The purpose of this study was to quantify the magnitude and nature of the injury problem in alpine skiing and snowboarding in New Zealand, determine the utility of two snow-sports injury databases, and inform the development of the national injury-prevention strategy (132). An understanding of the coding, classifications and terminology used in each database is the first requirement for undertaking a study that compares data (134). ACC used a single diagnosis code for an individual claimant; multiple injuries were not captured in the code. The compact hierarchy of medical codes were developed by Dr James Read in 1983 to cater for computer systems that had limited memory. Discordance relating to diagnosis may occur when assigning the Read code, and the code may also be applied incorrectly (135-138). In New Zealand there has been no systematic education for health professionals on how to use Read codes, this lack of education has added to

concerns that diagnostic coding errors may occur (137). However, missing diagnoses in the ACC database of <2% would not be an issue for assessment of trends in injury incidence.

The NID used simplified diagnostic codes for up to three injuries for one individual, with a four-part number and letter system for status, body part injured, side and condition. These nomenclatures added an element of sophistication and provided description of individual skiers or snowboarders who had multiple injuries. The small percentages of NID coding errors were seemingly typographical. Use of status 1 (critical problem with an immediate threat to life) as opposed to status 0 (dead) may have been due to patients being under resuscitation at the time of handover to the helicopter emergency medical service. Missing diagnoses in the NID database of <1%, as for the ACC, would not be an issue for assessment of trends in injury incidence.

Statistical methods have been designed to support comparison of injury incidence in studies of snow sports (51, 53, 139, 140). When comparing studies consideration needs to be given to the fact that some jurisdictions only include injuries that have been assessed and diagnosed by medical practitioners and other areas may only analyse ski patrol data. Depending on what data is entered into the incident database the number of injuries and patterns of injury may increase or decrease. Medical practitioner incident data may have less minor injuries than ski patrol data. For example, a skier suffering a minor laceration from a ski-edge may only require first aid, not require suturing, and therefore, will not see a doctor. In New Zealand regardless of the staff skill mix lacerations were recorded as soft tissue injuries in the NID. This reporting culture may lead to an increased proportion of soft tissue injuries when compared with other studies. Importantly, there was no difference in accuracy of data entry when comparing small New Zealand ski areas staffed solely by ski patrollers and large ski areas staffed by a mixed medical team. These findings correlate with Canadian analysis of ski patrol information quality (52).

Norway has a central registry representing 53% of skier/boarder days; 1.3 injuries per 1000 skier/boarder days occurred in the 2008/2009 and 2009/2010 seasons (141). In a study of 10 French ski areas in 2007 and 2010, Laporte et al

(9) found that incident rates fell from 2.8 to 2.4 per 1000 skier/boarder days. Shealy et al (47) found that the weighted USA skiing incident rates in national ski areas association data declined from 3.1 in 1980 to 2.5 per 1000 visits in 2010. The NID incident rates for skiers and snowboarders treated at ski areas in New Zealand were higher than France, Norway, and the USA.

The substantially higher injury rate in the ACC compared with the NID represents a “bypass effect”. This effect is most likely due to evolving symptoms leading to first presentations occurring off the hill and the no-fault accident compensation system that covers personal claims. For example, symptoms of concussion may not develop immediately following an incident on the snow. Injured international skiers and snowboarders are unlikely to return home for first treatment as ACC covers treatment costs and New Zealand is an international flight away from other countries. Ski areas located in large continents are likely to see bypass as injured skiers and snowboarders return to their state or country of origin, making it difficult to capture this group of injured.

The ACC system has been heralded as a world-leading solution when comparing medical systems that have burgeoning costs, but it has also been criticised for its potential for false claims by individuals who did not sustain an acute injury in the activity that was registered in the claim (142, 143). It seems unlikely that there would be a substantial misattribution of injuries to snow sports. However, the ACC system may promote claims for minor injuries where the individual in a user pays environment possibly would not seek treatment. Injured individuals can make a personal injury claim with a medical practitioner, physiotherapist or other ACC accredited health provider. The choice of treatment modality may in part explain higher injury rates in the ACC data. For example, with universal insurance cover provided by ACC a skier or snowboarder with back strain can present directly to a physiotherapist or chiropractor. Assessment and treatment incurs no cost or a low cost surcharge. In other health systems the back sprain incidence may be lower as skiers and snowboarders opt for self-management rather than registering as injured.

High proportions of knee sprains in skiing were found in recent epidemiological studies (8-10, 48, 141). The large numbers of knee sprains

bypassing mountain clinics in New Zealand highlight that the problem is greater than previously considered. Delays in seeking assessment and treatment for sprains can be explained by swelling evolving over time, increasing limitation of movement, and difficulty with managing pain. Grades of medial collateral ligament injury provide a possible explanation for bypassing mountain clinics (144). Grade I knee injuries maybe painful in the days after skiing but have no laxity and would probably not limit a skier getting off-the-hill without assistance. Grade II knee injuries involve separation of the collagen fibres of the medial ligament, have partial laxity and may involve the joint capsule, anterior and/or posterior cruciate ligament. Depending on the degree of disability and laxity, grade II medial collateral knee ligament injury may not present at mountain clinics or seek assistance from ski patrollers for extrication by toboggan. However, it is likely that grade II injured individuals would have difficulty getting on and off a chair lift. Grade III medial collateral knee ligament injuries are a severe injury that would limit capacity to continue skiing. The complete rupture that occurs in a grade III injury, lax joint and increased chance of haemarthrosis would mean that this group of injured skiers would likely present to ski patrol on-the-hill. Skiers with grade I or grade II injuries possibly take a wait and see approach to see what level of disability exists in the days following skiing. There was no difference in the definition of a sprain in the NID and ACC coding that could lead to an alternative explanation for the high proportion of knee sprains in the ACC data.

Both databases indicated that fractures of the lower leg were more common in skiers than snowboarders. The sharp decline in lower-limb fractures seen after the invention of the dual-direction ski binding in the 1970s' and 1980s' has not been sustained (64, 70, 81). Poor ski-binding maintenance, incorrect release settings, ill-fitting ski boots, changes to skiing style, and skiers unprepared for the trajectory of the carving ski are possible explanations for the continued issue of fractures of the lower leg.

The ACC and the NID reported higher proportions of wrist fractures in snowboarders when compared to skiers, this is consistent with findings in other studies (145, 146). The mechanics of falling on an out-stretched hand and frequency of falling when snowboarding (particularly for novices) explains the difference in injury proportions (147). Interventions to reduce the incidence of wrist

fractures in snowboarders could include instruction on staying upright, instruction on how to fall, and increased use of wrist protectors (148).

The proportions represented by concussion in skiers and snowboarders were similar. Further research is needed to describe the nature of head injuries in skiers and snowboarders in New Zealand. In the interim, analysis of head injuries elsewhere has provided sufficient evidence for promoting the wearing of helmets (101, 109, 149).

### **3.1.5 Conclusion**

Researchers informing the development of injury prevention interventions should not rely solely on one injury database. Bypass injury rates are needed to determine the true magnitude of the injury problem in skiing and snowboarding. Insurance databases are a relatively blunt tool for determining behavioural, equipment or environmental risk factors. Mountain-based epidemiological studies provide the detail required to inform injury-prevention initiatives. Increased understanding is needed on the demographic of skiers and snowboarders who delay seeking treatment, as early intervention may reduce severity and enhance recovery.

## **Part 2: New Zealand snow sports injury trends over five winter seasons 2010 – 2014**

### **3.2.1 Introduction**

Injury surveillance is a requisite for understanding the injury problem in alpine skiing and snowboarding (17). Historically ski areas have monitored incidents in-house and Ski Areas Association New Zealand (SAANZ) has determined collaborative injury prevention endeavour with the support of technical reports. In 2005, all ski areas moved from recording injury incidents on a SAANZ paper-based incident reporting form to a computerised incident reporting system managed on behalf of SAANZ by the New Zealand Mountain Safety Council. Electronic incident data collection made it possible to undertake this first longitudinal skiing and snowboarding injury study. The findings from this study will provide SAANZ with more comprehensive evidence to determine where injury prevention energy and resources should be focused.

### 3.2.2 Aim

Describe the injury rates and trends in snow sports in New Zealand over five winters to inform the development of a national injury-prevention strategy.

### 3.2.3 Methods

The Auckland University of Technology ethics committee approved the study - reference 14146. Ski patrollers, nurses, doctors, and radiographers completed incident-reporting forms for all injuries at all commercial ski areas throughout New Zealand (see, Appendix II). Anonymised data were entered into the electronic database each week of each winter season over five years. The NZ Mountain Safety Council maintained the National Incident Database (NID). SAANZ provided ticket sale records and season pass use for each ski area. Demographic data from SAANZ national consumer satisfaction surveys (2007 – 2009) were supplied in excel<sup>1</sup>. Bare-head and helmet wear counts were undertaken at chairlifts at two major ski areas in 2010 and 2015 (see protocol, Appendix III). Retrospective analyses were performed with the Statistical Analysis System (SAS). Uncertainties in the true values of the outcomes were assessed using magnitude-based inferences. For precision, 99% confidence intervals were computed in SAS. Six approaches were taken in the analyses. Trends in annual incidence rates per 1000 skier/boarder days were determined by summing the injuries at each ski area for each year, then modelling the count in each year with Poisson regression using ticket sales and estimated season pass use. The proportions of skiers, snowboarders, females, and males were determined in excel using SAANZ customer survey data supplied by Datapro (n= 25,910).

The effect of snow conditions and visibility on predicting injury types was analysed by limiting the data to the six major ski areas that had 82% of the skier/boarder days. As there were always injuries on any day that the ski area was open, this strategy avoided the bias that would arise from a given snow or sky

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<sup>1</sup> DataPro Solutions Limited designed customer satisfaction surveys, software and performed analyses for SAANZ. Ski area staff at all commercial ski areas surveyed customers.

condition reducing the injury rate such that no injuries occurred on some days. Hard snow or icy conditions existed when a ski patroller in ski boots could not make an impression in the snowpack. The soft or spring conditions description was used on days when the surface easily permitted leaving a ski-boot impression in the snow. Cloud cover provided effect of visibility data on injury incidence. Clear skies or scattered cloud cover determined good visibility. Poor visibility was determined by overcast conditions with full cloud cover leading to flat light or white out conditions with snow falling, mist or rain.

Logistic regression was used to analyse the effect of snow condition, visibility, skiing or snowboarding activity, and ability on the proportions of a given type of injury (e.g. head) and type of incident (e.g. falls, jumps, collisions). Deaths were counted. Injured skiers' self-reported when the ski binding released during the incident or did not release. Skier accounts of the ski binding pre-releasing in normal skiing manoeuvres were also included in the three level analysis of the effect of binding release. Probabilistic terms were used to describe the true value of changes in the mechanism (type of incident) over the five-year period. Where the true value could be substantial in both a positive and negative sense, the result was unclear; otherwise results were clear and the inference was described as likely trivial, possibly trivial, trivial, likely or a very likely increase or decrease (133).

The effect of helmet use on head injuries (cases) was determined by using other injuries as controls; a method previously applied in an investigation on the relation of head, face and neck injury in skiers wearing helmets (111, 140). A hazard ratio was obtained using a Poisson regression model of those that were head injured (using helmets)/(those not using helmets) divided by those that were non-head injured (using helmets)/(those not using helmets). The effect of wrist protection was examined in the same manner. Log of the counts, the dependent variable, the Poisson distribution (not the binomial distribution) invoked to account for the sampling variation in the counts, and the effect of the risk factor estimated as a ratio of counts of injured to uninjured individuals in exposed and unexposed subgroups (150).

### 3.2.4 Results

Over five winters 5,861,643 people were active in snow sports at New Zealand ski areas and 18,382 incidents were registered. New Zealand injury trends per 1000 skier/boarder days were 3.2, 3.3, 3.4, 2.7 and 3.1 respectively (2010 – 2014). There was most likely a trivial decline in injuries over this period (-3%, 99% confidence interval -9 to 3%). The proportions of people active in each sport were determined from 25,911 SAANZ surveys: 61% skiers, 32.4% snowboarders, 6.6% both ski and snowboard. No data was collected on the number of people tubing at ski areas.

Knee injuries were the most common injury overall (see Figure 3.2). Over two thirds of knee injuries occurred in skiers when compared with snowboarders and others (tubing/hiking) (76%, 21%, and 3% respectively). There was no significant difference in the frequency of back injury between skiers and snowboarders; 36% occurred in the cervical/thoracic region and 64% in the lumbar/sacral region. Wrist injuries were more common in snowboarders (80%). Snowboarders accounted for 52% of the head injuries, skiing 43%, and 5% were attributed to other activities. Shoulder injuries occurred more often in snowboarders (61%). Clavicle injuries were also more prevalent in snowboarders (64%). Conversely, 74% of injuries to the lower leg occurred during skiing.

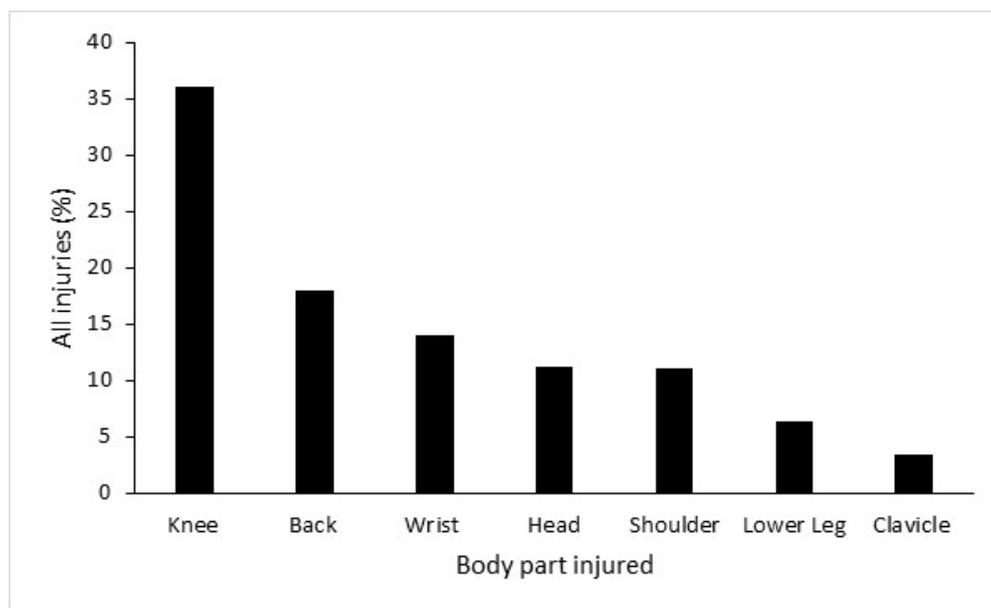


Figure 3.2: Body part injured by snow sports.

SAANZ customer survey data indicated that the percentage of male skiers was 53%, female skiers 47% compared to 61% male and 39% female snowboarders. Female skiers injured the knee more frequently than male skiers (65% vs. 35%). Non-release of the ski binding resulted in knee injury in skiers more often than release (see Table 3.1). More knee injuries occurred in soft snow conditions than hard (55% vs. 45%). The rates of knee injuries in either non-release or release were highest in intermediate skiers (45%), followed by novices (30%) then advanced skiers (25%).

Table 3.1. Equipment effects on knee injuries by snow surface condition and skier ability.

		Difference (Non-release/ Release)		
Surface	Non-release	Release	99% CI	Inference
Advanced Skier				
Soft snow	30.7% (n=430)	21.2% (n=420)	1.5; 1.2-1.7	↑***
Hard snow	27.7% (n=415)	12.9% (n=364)	2.2; 1.7-2.7	↑*****
Intermediate Skier				
Soft snow	44.9% (n=847)	29% (n=734)	1.6; 1.4-1.7	↑*****
Hard snow	37.2% (n=675)	23.1% (n=606)	1.6; 1.4-1.8	↑*****
Novice Skier				
Soft snow	46.8% (n=662)	38.2% (n=448)	1.2; 1.1-1.36	↑**
Hard snow	36.4% (n=495)	33.3% (n=315)	1.2; 1.1-1.36	↑*
N.B. Asterisks indicate effects clear at the 99% level and likelihood that the true effect is substantial, as follows: *possible, **likely, ***very likely, ****most likely.				

In 2010, 42% of skiers and snowboarders wore helmets; this increased to 83% in 2015 (skiers 84% and snowboarders 79%). Concussion very likely increased

over the five years (1.29, 99% CI 1.06 – 1.57). By age, 24- 32 years olds were less likely to be wearing a helmet when head injured (see Figure 3.3). The mean ages for each quartile were 12yrs (SD 3), 20yrs (SD 2), 27yrs (SD 2), and 47yrs (SD 10).

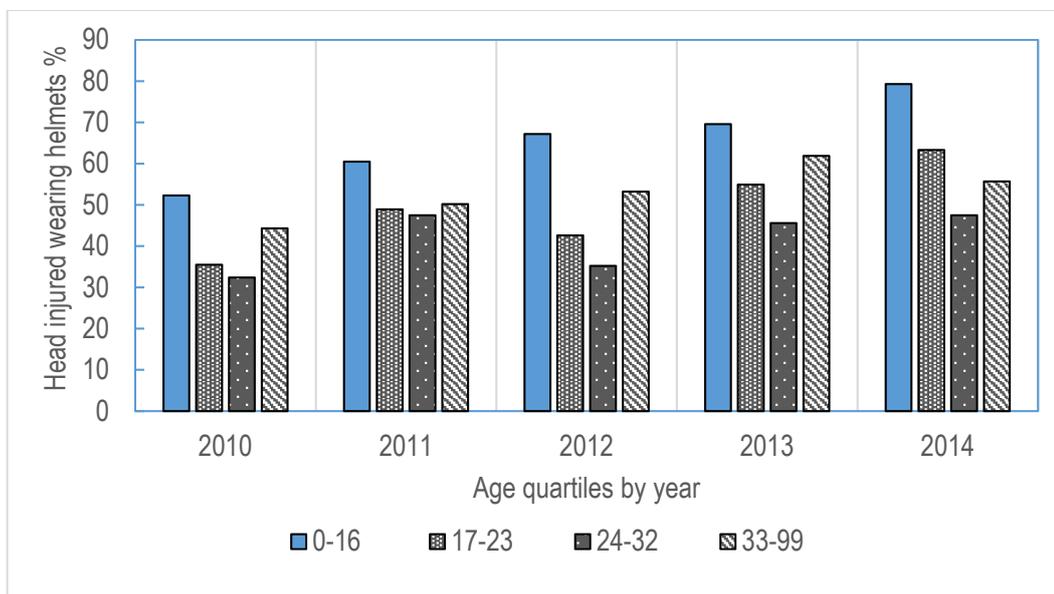


Figure 3.3: Head injured wearing a helmet by age group and year.

Head injury was higher in advanced and intermediate skiers wearing helmets than novices; 23%, 25% and 10%, respectively. For helmet wearing snowboarders' head injury increased in advanced, intermediate and novice snowboarders by 41%, 29% and 30%, respectively (when compared with those not wearing a helmet). Overall, there was a 26% increased risk of head injury in skiers wearing helmets (hazard ratio 1.26, 99% CI 1.05 – 1.52) and a 36% increase in head injury in snowboarders wearing helmets (hazard ratio 1.36, 1.05 – 1.52).

There was a very likely increase in wrist injuries in intermediate snowboarders in hard snow when compared with soft snow conditions (hazard ratio 1.3, 99% CI 1.17 – 1.45). Novice snowboarders had a possible increase in the likelihood of wrist injury in hard snow conditions (hazard ratio 1.12, 99% CI 1.02 - 1.21). Regardless of whether snowboarders were in a terrain park or in open mountain terrain, wrist protection was most likely beneficial in preventing wrist injuries (hazard ratio 0.65, 99% CI 0.54 – 0.79).

The combined skiing and snowboarding results for types of injury are detailed in Figure 3.4. Fractures declined by 0.3 per 1000 skier/boarder days. There was no decline in the incidence of concussion, dislocation, soft tissue injuries or sprains.

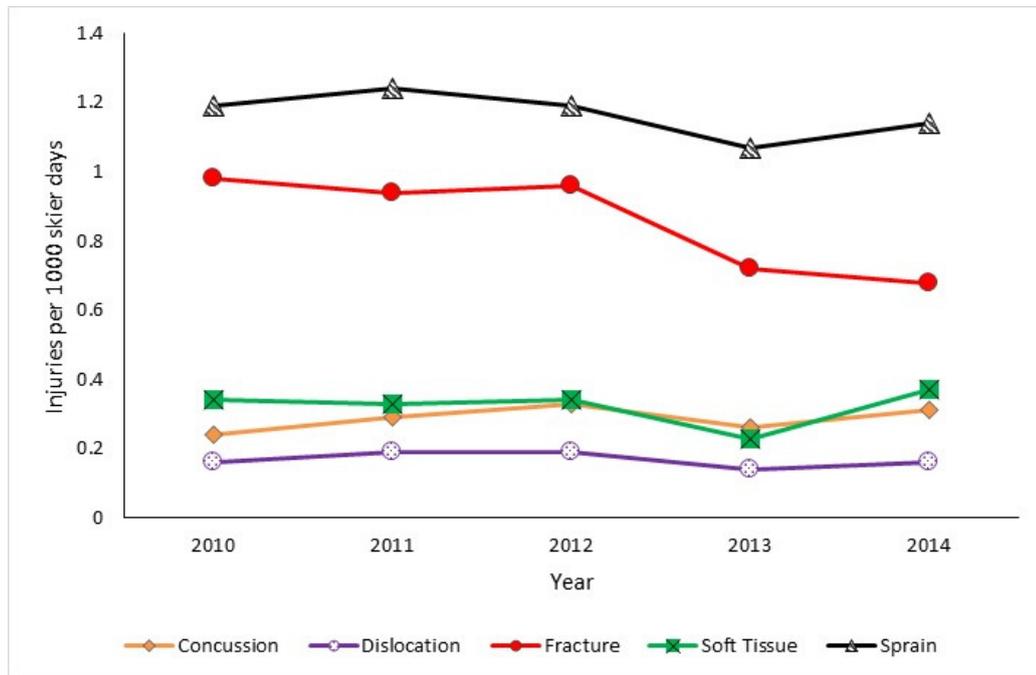


Figure 3.4: Types of injury in skiing and snowboarding.

Falls accounted for 74.3% of incident types with no difference between skiers and snowboarders; collisions 9.6% - snowboarders were more commonly injured in collisions than skiers 34% vs. 58% (8% tubing or other activity). In 2010, 2 skiers and 1 snowboarder died, 2 of 3 were not wearing helmets. In 2013, another snowboarder died attempting to retrieve a snowboard. All 4 deaths involved catastrophic sliding falls in hard snow resulting in severe injuries that included the head.

The proportion of injuries attributed to jumps were 7.3%; man-made terrain features 5.3%; lift accidents 2%, and sliding whilst tubing or other incident types accounted for the remaining 1.5%. When considering mechanisms of injury using counts of injury types in each year there was a likely decrease in jump-related injuries (0.83, 99% CI 0.69 – 0.99), likely trivial decrease in falls (0.94, 99% CI 0.88 – 1.00) and the inference for collisions was unclear (1.00, 99% CI 0.83 – 1.22).

In terms of sky cover, there was 2.5 times more likelihood of injury in good visibility conditions (hazard ratio 2.5, 99% CI 1.97 – 3.19). In good visibility advanced skiers most likely increased injuries to the lower leg when the snow was soft versus hard (hazard ratio 2.06, CI 99% 1.55 – 2.7) and a likely increased probability of knee injury in soft snow versus hard (hazard ratio 1.28, 99% CI 1.11 – 1.48). In poor visibility, the probability that advanced skiers injured the lower leg in soft snow versus hard snow was a likely increase (hazard ratio 1.63, CI 99% 0.94 – 2.71). Soft snow conditions led to a very likely increase that advanced skiers sustained knee injuries (hazard ratio 1.59, 99% CI 1.16 – 2.11). Intermediate skiers in good visibility had a very likely increase in lower leg injury (hazard ratio 1.34, CI 99% 1.12 – 1.60); however, in poor visibility and soft snow the results were unclear (hazard ratio 1.02, CI 99% 0.73 – 1.40). For the knee there was a very likely increase of injury in intermediate skiers when the visibility was good and the snow was soft (hazard ratio 1.27, CI 99% 1.16 – 1.39). In poor visibility, intermediate skiers had a most likely increase of injury (hazard ratio 1.63, 99% CI 1.38 – 1.89). Novice skiers had similar findings to intermediate skiers when the visibility was poor.

### **3.2.5 Discussion**

New Zealand injury trends per 1000 skier/boarder days were higher than the 2.5 per 1000 skier/boarder days in the USA National Ski Areas Association (NSAA) ten year interval study (3.2, 3.3, 3.4, 2.7 and 3.1 respectively) (47). An overall target of less than 2.5 injuries per 1000 skier/boarder days in New Zealand (SAANZ national incident data) is clearly desirable. There was no known reason for the decline of injuries in the 2013 season; this decline was not sustained. The influence of the snow-pack on injury incidence will need to be considered and accounted for in future statistical analysis so that the effectiveness of injury prevention interventions can be separated from natural events. More skiers than snowboarders were active on the slopes. The SAANZ customer satisfaction survey data (2007 – 2009) indicated that there were slightly more male skiers than females and those males dominated snowboarding. The lack of 2010 – 2014 demographic data is a potential limitation; however, major changes in the make-up of the snow sports population are unlikely.

Nearly one third of NZ adult skier injuries involved the knee, with female skiers at greater risk of knee injury than males. These findings align with earlier studies (47, 48, 64, 67). Since the introduction of the carving ski in 1993, female skiers have dominated knee injury trends. For females, the risk of knee sprain was 2 to 3 times higher in females and there was an even greater risk of anterior cruciate ligament rupture. Ski-binding release settings that were too tight were associated with knee and lower leg injury in all skiers (49, 83). One solution found to reduce knee and lower leg injuries was regular equipment torque-testing and set-up checks (151). The New Zealand snow sports industry need to invest in torque-testing equipment to determine that ski-binding-boot systems are not too tight and equipment is in good working order (90-92, 152-154). The analogy of an annual motor vehicle warrant of fitness could be used to encourage skiers to have ski equipment regularly torque tested and tuned.

Presently there are no recommendations from standards organisations to account for snow surface conditions when setting up the ski-binding boot system. Given the increased probability of injury to the lower leg and knee in soft snow, adjusted lower settings that promulgate release when skiing in soft snow surface conditions seem logical. The release results in this study add further weight to the need for vigilance during ski-binding set-up. Changes in weight, growth, and skiing style need to be factored into pre-season release setting calculations. Advanced skiers may no longer have the fitness level or the desire to ski at speed aggressively on steep pitch in all snow conditions and as such, these changes in skiing style warrant lower ski-binding release settings. Further public education on safe ski-binding set-up is needed. Researchers working with ski equipment manufacturers also need to continue the quest for solutions that will protect the knee whatever the direction of the injurious force (84, 124).

Skiers and snowboarders had similar rates of back injury, with nearly two thirds of these involving the lumbar sacral region. An earlier New Zealand study in the Southern Lakes region (1991 – 2002) found a higher proportion of skiers had burst/compression fractures when compared with snowboarders. The most frequently fractured vertebrae were found at the thoracic-lumbar junction at the posterior base of the rib-cage (62, 146). The change in the injury pattern to the lumbar-sacral region is possibly due to the advent of twin tip skis and snowboards

leading to more aerial manoeuvres. The Swiss found that the majority of severe spinal injuries (n=63) admitted to a tertiary trauma centre were related to skiing, with over half of all spinal injuries sustaining injury at two or more levels (96). Injury prevention interventions to decrease back injuries will need to consider the changes that have occurred in the way people ski and snowboard.

Helmets have been proven to dampen forces and protect the head from injury when skiing or snowboarding with no increased risk of neck injury (109, 111, 155-158). Helmets are designed to limit linear acceleration to no more than 300 g following a 2.0 m drop onto a steel surface (translating to 27.7 km/h). Helmets have been proven to reduce head abrasions, lacerations, and mild concussion (111). The increase in concussion rates raises concern that those wearing helmets are overestimating the protective capacity of the helmet and are taking greater risks with speed and/or jump-height than those not wearing a helmet. More research is needed on risk-taking behaviours (158, 159).

Death was attributed in part or in-full to traumatic brain injury in the four tragedies at New Zealand ski areas. After the 2011 inquests, for three of these deaths the Coroner recommended that ski areas actively promote the use of helmets when skiing or snowboarding (mandatory use was not included in the court summations). Helmet wear has been promoted in the SAANZ snow sports injury prevention strategy and the new snow safety code (132). Further work is warranted on trends in head injury severity using Glasgow coma scale scoring (these head injury observations are entered in the patient report section of the SAANZ incident reporting form but not entered in the NID). To continue to improve the design of snow sports helmets further understanding of the torsional and coup-contrecoup forces that brain tissues are exposed to are also needed (160).

Other countries have found similarly high rates of wrist fractures in snowboarding as were reported in this study. Up to a ten-fold increase occurred in forearm injuries when compared snowboarding to skiing (60, 147, 148, 161). Most wrist fractures occurred within the first 7 days of learning to snowboard. We found there was a very likely increase in wrist injuries in snowboarders that were intermediate and a possible increase in novices in hard snow conditions. More education on safe techniques for riding in hard snow conditions is needed for

intermediate and novice snowboarders. Development of a national snowboarder education programme has been promoted in the strategy to counter fall mechanisms that result in wrist fractures (147). Wrist protection was clearly found to be beneficial in preventing wrist injuries. Presently there is no international standard for snow sports wrist protectors. In New Zealand, some of the wrist protectors are potentially too short, finishing proximal to the wrist joint. Short wrist guards have the potential to transfer the force to forearm and cause breaks (162). Further investment and promotion of wrist protection will occur in New Zealand when the international standard for snow sports wrist protectors has been agreed on (148).

Snow surface condition and visibility information informs ski area decisions on whether to open all runs. When runs are open regular updates on snow surface conditions matched to ability are needed so that trail choices are a better match for the skier or snowboarder, particularly the novice and intermediate. When mountain weather conditions are changeable, good vision is needed for hazard identification. The visual deficiencies created by foggy goggles, inappropriate lens colour, or no optical correction may account for injury on poor visibility days. Decreased visual acuity has been found to delay reaction times and ability to take evasive action (163-165). Regular eye testing and wearing prescription eyewear whilst skiing or snowboarding has been included in the strategy. GPS mapping that pinpoints where incidents are occurring aligned with snow surface conditions and visibility information could also provide opportunities to mitigate injury. An increased provision of equipment-related information to at risk groups such as check your set-up, sharpen edges for hard snow conditions, and choose the correct wax to help glide and reduce friction would also be of value (125).

### **3.2.6 Conclusion**

Injury trends in snow sports in New Zealand indicate that there was no significant decline over five winters. Future injury prevention priorities need to be based on injury surveillance. Going forward, strategies will be needed to counter, “the higher or faster you go, the harder you fall” phenomena. The high proportion of advanced skiers and intermediate skiers with knee injuries that occurred with non-release in both hard snow and soft snow conditions raises concern that ski-binding release

settings were too high. To help mitigate equipment-related injury risk skier education on correct set-up is needed alongside industry adoption of international equipment torque testing and practice standards. Knee injuries that occur skiing also beseech an equipment design solution. Using helmets unfortunately was not a panacea for decreasing the number of head injuries but likely reduced the gravity. Further research is needed on head injury to understand why those that are wearing helmets are suffering more head injuries than those that are not protected by a helmet. Risk compensation was one possible explanation. Ability to avoid hazards in poor visibility could potentially be enhanced by improving technique, regular eye testing, and for those that need it, wearing prescription eyewear on the snow. Wrist protectors were clearly of benefit in reducing wrist fractures in snowboarders. The release of the international snow sports wrist protector standard is eagerly awaited so that wrist protectors with the proven correct dimensions can be promoted. The 4 deaths that occurred were a sobering reminder that injury prevention efforts cannot diminish. No deaths would be a more than reasonable goal; however, due to human fallibility and the unpredictable challenges faced in mountain terrain this may never reach zero. The development of snowboard brakes could reduce risk of injury during retrieval of a runaway snowboard. Furthermore, when ski area staff open terrain for the public, full account needs to be taken of hard snow surface conditions that increase the risk of sliding falls.

### **3.2.7 Limitations**

The SAANZ national customer satisfaction survey program was discontinued in 2010. SAANZ reports for 2010 – 2014 estimated that these demographics were unchanged; however, there was no data provided to support this assumption. Changes in the make-up of the active snow sports population may have occurred over the years of this study. These surveys may also have had interviewer bias, with one group being interviewed more than another group. There was also no data on the number of people that declined to be interviewed. To effectively target at risk groups, demographic data (skier, snowboarder, female or male) needs to be routinely collected at ski areas on each day of operation and included in future analysis of National Incident Data. Two major ski areas only provided head injury and bare-head count data. Counts are needed at all ski areas to more accurately determine the effect of increased helmet use.

## CHAPTER 4 – SYSTEMS RISK

### Prelude

The most common snow sports injury requiring a prevention solution was knee sprains that resulted in partial or complete laxity of the joint structure. Chapter 2 data found that ski-binding release settings that were too tight were associated with ligamentous injuries of the knee and ankle. Tight ski-bindings were also a risk factor in bony injury of the tibial plateau, tibial shaft and the fibula. Chapter 3 identified that when comparing skiing and snowboarding injuries two thirds of knee injuries occurred whilst skiing. Overall one third of New Zealand adult skiing injuries involved the knee, with females at greater risk than males. Advanced skiers were 2.2 times more likely to sustain a knee injury with non-release of the ski binding in hard snow surface conditions than when the ski binding released. Organisations need to work to prevent accidents. Correctly, set-up equipment is one form of prevention. There was no local data on snow sports rental systems and ski technician practices. In order to prevent skiing knee and lower-leg injuries that occur in non-release, it is important to examine equipment set-up. Knowledge on the status of practice can assist ski area management to improve systems. This chapter examines ski area and off-hill ski rental services and as such contributes to identifying risk factors that are potentially part of causation of injury (TRIPP stage 2).

## 4.1 Introduction

International standards provide the ski industry and snow sports participants with the framework for ensuring supply of snow sports equipment of good quality, increased interoperability of products, service quality and equipment-related safety practices.(90-93, 166, 167) There is presently no mandatory requirement for members of the Ski Areas Association of New Zealand (SAANZ) or the New Zealand Snow Industries Federation to comply with the international snow sports equipment standards. Standards New Zealand is a member of the International Standards Organisation (ISO) but has no representation on the Sport & Recreational Equipment Committee T83 or the sports equipment subcommittees for ski bindings (S3) or skiing and snowboarding (S4). Also of note is that New Zealand does not have technical membership with the other international standards organisation, the American Society for Testing and Materials International (ASTM). SAANZ members have worked together over decades on projects to enhance skiing safety, momentum has changed dependant on the work of enthusiastic individuals or the commercial challenges of the winter season. That the safety actions of ski areas cannot be quantified by evidence-based research is a dilemma as what is being done well cannot be shared and it is not known where improvement is required. The steady increase in United States ski rental facilities complying with ASTM F1064-03 was an important part of the decline in the lower leg injuries between 1972 and 1989. However, concern was raised in 2006 that the ski industry began to look at the newly established standards as a ceiling for ski areas safety efforts, not the baseline, and that a gradual decline was occurring in service that was contributing to injuries. This study explored whether New Zealand ski rental shop practices for set-up of ski equipment benchmarked to international standards and provided evidence for SAANZ on-going efforts in injury prevention.

## 4.2 Methods

Electronic searches of Pubmed, Medline, SportDiscus, Scopus, and Standards Organisation databases were performed for standards related to alpine skiing. Standards that were not current were excluded<sup>2</sup>. Literature review results informed the development of questions for the survey and interviews.

Ethics approval for a cross-sectional study of all member organisations in Ski Areas Association New Zealand (SAANZ) and the New Zealand Snow Industries Federation was gained from AUTECH, the university ethics committee (Reference 07/158). Anonymised numbered questionnaires for ski technicians were delivered personally to all major ski areas (93% skier/boarder days) and large off-hill rental facilities in 2007, and delivered by post in 2009 (see, Appendix IV). The term ski technician broadly described the rental shop workforce (it is noted that in some settings this term was reserved for those that have comprehensive roles of set-up that include mounting ski bindings, maintaining edges and bases, torque-testing, and repairing the S-B-B systems). Recorded interviews were undertaken with key personnel based on 14 set questions (see, Appendix V). The key personnel were senior staff that were either directly involved in ski-binding-boot set-up or the management of service quality. Rental shop managers and operations managers or general managers at all major ski areas were also interviewed. Thematic analysis of interview data was subsequently completed (see, Appendix VI).

## 4.3 Results

Of the 424 surveys circulated to all commercial ski areas in New Zealand and large off-hill rental facilities, 227 surveys were completed and returned (an overall response rate of 54%). The demographics of the rental shop workforce were 50% had more than three seasons' experience in S-B-B set-up, 22% one to three seasons experience and 28% were new that season. Interviews were completed with 23 key industry personnel (see Appendix VI). Interviews generally took 45 minutes.

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<sup>2</sup> The normative reference system within a standard provided search links to provisions in other international standards. Following reference documents triggered inclusion of the most recent edition. Typically, an international standard cross-referenced six other standards and revisions occurred approximately every five years, depending on design advances.

A high percentage of survey participants reported that ISO release selection tables were used to determine release values, but when asked separately about each parameter required to check during the set-up of S-B-B systems: age, height, weight, and boot sole length was not always checked (see Table 4.1). Only 10% of ski technicians surveyed used a torque-testing machine. These ski technicians worked at an off-hill rental shop in Queenstown. No commercial ski areas or other off-hill rental outlets used torque-testing machines or torque wrenches in pre-season testing, in-season testing, or during set-up.

Table 4.1: Responses of ski technicians to questions about ski set-up (%).

	<b>Yes</b>	<b>Sometimes</b>	<b>No</b>
<b>General</b>			
Use of release value selection table	85	13	2
Change of set-up practices in rush hour	4	42	54
Snow conditions taken into account	24	-	76
<b>Skier characteristics taken into account</b>			
Age	81	15	4
Gender	16	-	84
Physical condition (fitness)	47	31	22
Height	55	13	32
Weight	48	12	40
Beginner of 7 days skiing or less	37	-	63
<b>Checking of equipment</b>			
Ski-boot size	68	11	21
Ski-boot wear and tear	68	22	10
Ski-binding-boot compatibility	79	10	11
Ski-binding elastic travel in twist	79	-	21
Ski-binding elastic travel in forward lean	75	-	25
Data are proportions of those who responded to the item; missing values were <3%.			

In interviews, it was established that all ski areas had standard operating manuals for the rental shop; however, only one off-hill rental shop of the seven had an operating manual. Training for staff was mostly on-job coaching, and <50% received formal pre-season training. All respondents expressed a desire to have

more education from ski manufacturers, with the majority commenting that ski manufacturers appeared to have abandoned educational input on ski maintenance, testing, and correct set-up. Equipment service and on-going maintenance schedules for rental equipment were largely based on constant vigilance, with gear checked on- return for damage. One respondent noted, “Ski equipment is better manufactured than 10 years ago”. In the eruptions [on Mt Ruapehu in 1995–96] we replaced all the bindings, and now, with no rope tows, Cats [groomers] not dropping oil, and snow-making, there is less dirt and debris that can get into the binding – this could still be an issue on some fields”. Some, binding systems had replaceable anti-friction plates, toe-pieces and heelpieces, which were routinely inspected and replaced. Equipment was generally retired from the rental fleet after three or four years.

Approximately one third of respondents thought that a national stance was needed on determining skier type. Suggestions included using “conservative” rather than “beginner” as a description and providing a greater range of descriptors for type II skiers. Last time skiing and average number of days also needed to be factored into determining skier type. Beginner, intermediate and advanced were the most common terms used on rental documentation, not international standard skier type I to III classifications. Posters on skier type or general public information on correct set-up were not commonly displayed. Some ski technicians made additional adjustments for some at-risk groups. The decisions by ski-technicians to lower the release settings for at-risk groups were not based on guidelines in Standard Operating Manuals.

Manufacturer workshops were requested by two thirds of the respondents, and educational input from ski patrollers on injury patterns was suggested by approximately one third. Up to three respondents requested development of each of the following: user-friendly release-value selection tables without confusing arrows, guidelines on lower release settings for at-risk groups (gender/female, light-weight males, beginners of less than 7 days skiing and those in poor physical condition), direction on additional adjustments for wet heavy snow conditions, specific education on S-B-B set-up for children, boot-fitting education, and injury prevention education.

Suggestions for education packages for skiers were diverse and mostly singular; however, approximately one third of respondents thought Information technology was under-utilised, and that unsafe vintage ski equipment should be removed from sale (predominantly sold in ski-swaps' and on-line sales). There appeared to be two viewpoints on where skier education should start: in rental shops, as this was the first-place that those who are new to snow sports congregate, versus in other mountain facilities, where it was not so busy. One respondent noted that customers often did not understand why they needed to divulge private information like weight, and thought that simple messages needed to be displayed in rental shops on the importance of accurate information on skier characteristics to ensure correct set-up.

#### **4.4 Discussion**

The main finding in this study is that most rental shops did not test S-B-B systems with a torque device even though the international standards require torque testing. Three- to four-year rental- fleet replacement cycles were in place to ensure the supply of safe functional ski-bindings. However, without torque testing there is no guarantee that the equipment replacement cycles are supplying functional equipment. In the standards, S-B-B systems are withdrawn from service when the torque S-B-B is less than or greater than 45% from the reference point (Class III deviation). (90, 91) Manual checks in twist and forward lean test elastic travel, and confirm that the ski binding will return to centre. Ski technicians checked elastic travel most of the time; however, these checks do not replace torque testing.

The ISO release value selection tables were used by ski technicians across New Zealand. Inconsistency in acquisition of the skier characteristics for correct set-up was a key finding. The parameter of weight was not acquired over a third of the time: weight is an essential characteristic in determining release values. The ISO tables do not provide direction on lowering release settings for at-risk groups, yet, additional adjustments were frequently made for skiers in poor physical condition, sometimes for beginners, and occasionally for females. The French national standards organisation, AFNOR have lowered release values by 5 to 15% for groups that have a greater risk of lower limb injury: women, light-weight men (less than 57kg), beginners with less than seven days skiing, and skiers in poor physical

condition.(83) Some countries have adopted French recommendations on adjustment release values, creating unanswered questions for other skiing nations; it would be of value for all skiing nations to be on the same standards. Release values were changed by nearly a quarter of respondents in wet heavy snow conditions. Guidelines on additional S-B-B adjustments in wet heavy snow conditions would also be useful.

Skier type I, skier type II, and skier type III selection criteria were not commonly displayed in rental shops or described on rental documentation. Some ski areas procedures had technicians ask the skier if they were a beginner, intermediate, or advanced skier without defining these subjective terms; this practice creates the potential for incorrect categorisation of skier type by the skier, and set-up of an inappropriate release setting.

Omissions when checking equipment were also reported by some ski technicians. Proper release from ski-bindings depends on the dimensions and design of the ski-boot sole and the ski-boot heel.(168) Omitting wear and tear checks may lead to incompatible S-B-B systems. Snow cover in New Zealand ski areas in the Southern Alps and volcanic plateau of the North Island is affected by the maritime climate. It is not uncommon for skiers to walk over rocky surfaces in ski boots to get to the snowline, leading to accelerated wear. A boot sole when worn will not interface correctly with the ski binding, creating the potential for premature release. Respondents reported that replacement toe-pieces and heel-pieces were not always supplied by manufacturers with new ski boots and that importing these parts separately was expensive. Any delays in replacing toe-pieces or heelpieces could lead to incompatibility of the ski boot to the ski binding. An additional problem is a dirty ski-boot sole; dirt could render the anti-friction device ineffective and compromise release. The S-B-B interface could also be negatively affected if defective anti-friction devices are not replaced promptly.

One of the many challenges for skiers is to have the correct size of boot. Survey results indicated that some ski technicians did check boot size, and interview respondents noted that more education on boot fitting was needed. For large rental operations, ensuring a comfortable fit may be a level of service that is marginalised by the pressures to get numbers through the rental facility and out on to the slopes.

#### **4.5 Conclusion**

There is room for improvement in rental shop practices across New Zealand. International standards should be the base-line for good service.(90, 91) Direct involvement by New Zealand representatives in writing standards could lead to greater buy-in and translation of these standards to everyday practice. New Zealand rental shops need to be properly equipped with torque-testing machines or wrenches. Torque testing should be mandatory to ensure functional ski-binding spring and lever systems that work at the correct torque in twist at the toe-piece and in forward lean at the heelpiece. Consistent acquisition of all parameters for determining the correct release selection is paramount.(92) Understanding why all set-up steps need to be followed correctly is an important educational bottom-line for both the ski technician and the skier. More discussion at international standards bodies is warranted on the classification of skier type using contemporary unambiguous language. The different viewpoints on lowering release values for skiers that are at-risk of lower limb injury have the potential to confuse ski technician decision-making. Concurrence is needed on ski-binding release values for women, light-weight men, beginners with less than seven days skiing, and skiers in poor physical condition.(83, 166) Given that ski technicians are also making ski-binding adjustments in different snow conditions, guidelines are needed to inform these decisions. Translation of the international standards into skier education is vital, so that the customer demands torque testing and correct set-up.

#### **4.6 Limitations**

Research was undertaken late in the winter season. Pending closure of ski areas may have affected the sample and participation response rates.

## CHAPTER 5 - EQUIPMENT RISK

### Prelude

Snow sports rental shops cater for hundreds of skiers who place high demands on equipment. The previous chapter identified that less than 10% of New Zealand ski technicians torque tested ski equipment despite recommendation of this testing method by the International Organisation for Standardisation (ISO) technical committee S3 - Ski Bindings and ASTM International technical committee F27 - Snow Skiing. Wear may lead to ski-binding malfunction and metal fatigue; however, the rate at which the ski-binding ages and the level of equipment risk that skiers were exposed was unknown. The high incidence of knee sprains (ACC 33%, NID 54%) that were determined in chapter 3 add exigency to the need for solutions. This chapter adds to the causation data presented in the previous chapter (TRIPP stage 2) and activates TRIPP stage 3 – potential solutions. The chapter is presented in two parts: a review of literature on ski-binding engineering and associated equipment standards, and an evaluation of the effect of age on rental ski stock at one major ski area using torque testing

## **Part 1: Ski-binding engineering and associated equipment standards**

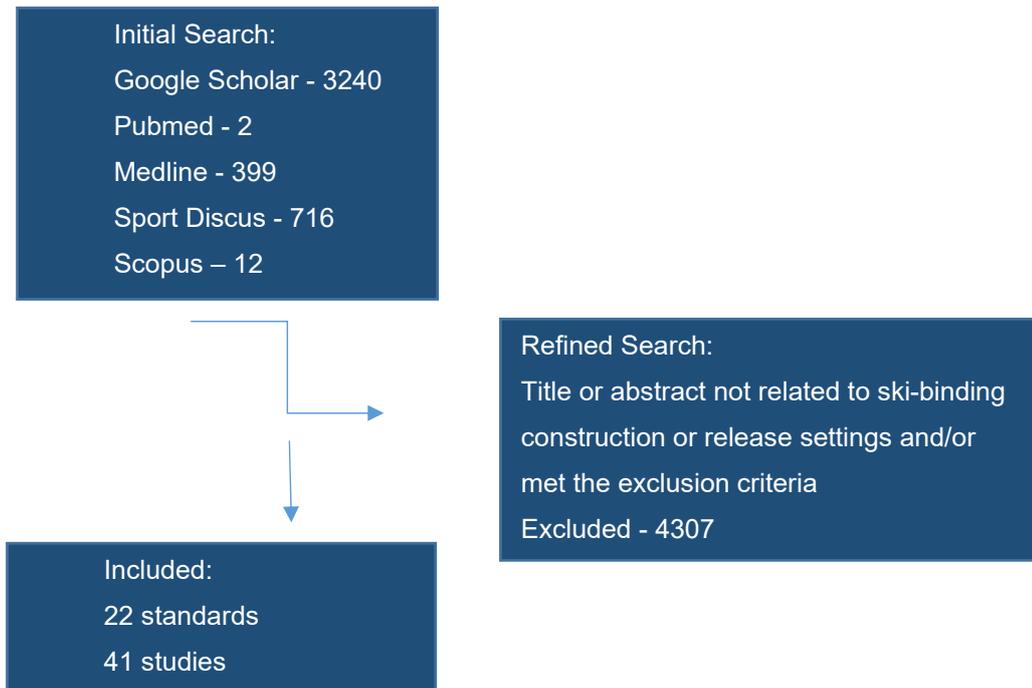
### **5.1.1 Introduction**

Improvements in the ski-binding-boot (S-B-B) equipment design, the introduction of equipment standards and correctly set-up S-B-B systems resulted in a reduction in alpine skiing lower leg injuries of 83% in the period 1972 to 1999 (8, 82, 89). The design improvements in the ski-binding had successfully protected the lower leg but alarmingly, in the same period knee injuries increased by 194% (11). Since the late nineties approximately one third of skiing injuries have involved the knee, with women at two to three times more risk than males (48, 77, 82). Also of concern is there has been an increase in fractures of the tibia and ankle, particularly in 12 year olds (9, 50). With these statistics in mind, potential causative factors are of interest.

Changes in ski length in the last three decades, binding design and inappropriate release settings have been identified as potential contributing factors to these aforementioned injuries (49). At a mechanical level, there appears to be no data in the literature, which considers the effect of equipment, wear and age on the effectiveness of the ski-binding spring and lever system. There also appears to be limited data on application of equipment standards (169). Lowering the ski-binding release setting for females was proffered as a solution for reducing knee injuries but the need for further research was highlighted (49, 83). Given this information, the purpose of this section was to identify injury risk-related knowledge gaps in the literature that might be linked to SBB engineering and standards.

### **5.1.2 Methods**

Database searches of Google Scholar, PubMed, Medline, SportDiscus, and Scopus were performed for studies (1993–2017) published in English, French and German related to ski-binding construction and standards using key words: alpine, ski, binding, boot, equipment, standards. Reference librarians sourced loan copies of standards held by the Auckland Public Library and purchased standards not archived in New Zealand. Regardless of year, earlier articles related to the establishment of ski-binding release settings were examined. Exclusion criteria: expired standards, cross country ski equipment, ski-board and snowboard. Search selection overview provided in Figure 5.1.



### 5.1.3 Engineering

The alpine ski went through revolutionary changes in the 20<sup>th</sup> Century, evolving from a transport device to a highly engineered system for recreational alpine skiing and downhill competition. This section addresses the current engineering features of the SBB system. To ensure that alpine skis would track smoothly, the plasticity of snow and deformation created by the ski and skier were considered in the design process as different snow surface conditions ultimately affect manoeuvrability of the ski (118, 119, 170). From 1993, the parabolic shaped skis with a narrow waist gradually replaced long straight conventional skis (56). The geometry changes in the parabolic ski occurred in the side-cut radius and the edge profile creating an easy turning ski (64, 84, 124). The side-cut of the ski affects the shape of the groove in the snow. Carving turns occur when the rear of the ski glides in the groove created by the front section of the ski. The change of profile in the parabolic ski resulted in a larger surface area of the ski staying in contact with the snow which in-turn allowed reduction in ski length. Shorter skis potentially were less stable at speed. New cushioning, bending and torsional features in ski construction reduced vibration and improved impact absorption. Advances in ski construction also resulted in lighter skis.

To link the skier (ski-boot) to the ski, retention systems advanced from leather strappings and cables to a safety binding that released when overload occurred (84). Degrees of freedom or planes that a ski-boot could release from the binding needed to account for the combination of loads created by the body of the skier and the kinetics of motion (171, 172). The dual-directional (two-mode) release binding became the mainstay design for recreational skiers. The heelpiece provides retention or release in forward lean. The toe-piece provides retention or release in lateral and medial twist. In release at to toe the boot pivots about an axis near the heelpiece (173). Anti-friction devices (AFD) support release of the ski boot from the binding (see Figure 5.2).



Figure 5.2: Alpine ski-binding component parts.

Expensive multi-directional bindings provide three modes of release at the toe piece: in, upward, or in a diagonal direction (84, 124). Mechanical or mechatronic ski-bindings with greater than four degrees of freedom were either at the conceptual, experimental or limited release to market stage. Advancing mechatronic solutions may lead to ski-bindings that sense injurious moments at the knee and trigger early release.

The release binding, originally described as a safety binding in equal measure includes safe ski-boots (174). To improve safety, thermo-plastic boots constructed in moulds replaced leather ski boots. Buckles replaced laces and secured the overlap of the plastic boot. Advances in liner materials improved thermal insulation, moisture absorption and comfort. The rigidity and increased height of the contemporary ski-boot restricted movement at the ankle and provided protection from lower leg injury (175). Canting adjustments in the expensive boot

range countered the valgus or varus position of the knee. The more neutral stance in the canted ski-boot possibly reduced the risk of cruciate ligament rupture and improved skiers edging capabilities (176). The addition of flexible rear spoilers in one ski-boot range was designed to reduce shear forces in the knee on jump-landing; however, there is no empirical evidence that this has occurred (84). Boot side-wall specifications ensured retention of the boot in the ski-binding (168).

#### **5.1.4 Impact of improved design**

Innovation and writing standards that quantify engineering advances in the S-B-B system has not happened in unison. Patents pending and standards organisation inertia has been muted as possible explanation for this mismatch (124). Manufacturers responding to market demands have driven changes in functionality of the SBB system. The competitive skiing codes of downhill, giant slalom, slalom, freestyle, and ski jumping have also exacted a driving influence for improvements in equipment precision. Some researchers have worked in the secretive product development environment to find the winning formulae. Collectively researchers involved in injury prevention in skiing have not kept up with the bio-mechanical implications of new S-B-B design parameters (84). With changes in equipment design the movements of skiing have changed; the predominant load in the turn is no longer on the outer ski and more evenly shared between skis (177). The radius of the turn with narrow waisted skis is smaller resulting in a lively ski. The manoeuvrable carving ski potentially places under prepared skiers on a trajectory that may increase risk of injury (64, 178). To remain balanced the skier needs to retain a central position rather than edging the downhill ski in the turn. Compared to conventional skis the parabolic ski results in the skier experiencing intensive co-loading of the outer and inner leg in the carving turn.

The present ski-binding design has only provided a partial solution for the complex load situations on the knee and lower leg. Limitations exist in release directions, along with constraints in the resetting behaviour and impact tolerance of the binding. ISO standard 9465 specifies lateral release under impact loading but there is no standard covering the dynamic behaviour of the heelpiece (88, 124, 179). The multi-directional toe-piece has provided an additional degree of freedom in the upward direction but no standard has accompanied this innovation (124).

There is also no definition in the ISO technical vocabulary for multidirectional ski-bindings with more than two degrees of freedom (180). Despite improvements in ski-binding design, release indicators were imprecise; the numbers did not reflect the actual torque. Invalid indicators were found in 59% of skiers equipment that had sustained lower leg injuries, a five-fold increase in injury risk (88). To trigger release from the ski-binding force needs to exceed the detent value of the setting and overcome the co-efficient of friction of the boot sole (82). Anti-friction devices lower the co-efficient and support release of the boot.

Well fitted boots, are an essential part of the S-B-B system as this denotes the pivot point found between the heel and the back of the boot (173). Importantly, the pivot positions along with the binding characteristics determine the combination of forces and moments needed to release the skier from the binding. Injectable ski-boot moulds used in production systems unfortunately do not cater for the anthropometrical nuances of an individual's anatomy and support all skiing movements (84). An ill-fitting boot may affect the pivot point position and lead to strain on the ACL during skiing (173). The ski boot angle may not align with the knee, lead to poor stance and increased risk of injury (181). Skiers that do not have neutral alignment of the knee and are knocked-kneed (valgus) or bow-legged (varus) may struggle to edge the ski. Canting adjustments in the ski boot may improve body position and provide some protection for knee ligaments. The canting features are only available in the expensive ski-boot range. For all skiers, the increased cuff height and stiffness of the ski-boot has provided increased ankle protection (182). However, for some individuals the height of the cuff may lessen plantar flexion and impede pressure distribution in the turn. Poor boot-fit in a rigid structure could negatively affect comfort and sensory motor control by impinging nerves in the foot. In-turn a tight boot with pressure areas could affect skiing style, affect triggering binding release and increase risk of injury.

### 5.1.5 Standards

An overview of the 22 current standards associated with the ski-binding-boot system provided below summarise ski equipment safety considerations (see Figure 5.3).

ISO	ASTM	Others
ISO 554-1976. Standard atmospheres for conditioning and/or testing - Specifications	F473-96/03 (re-approved). Standard specification for Binding Mounting Area Dimensions on Alpine Skis and Bindings	French - AFNOR AFNOR FD S 52-748.  Alpine ski bindings - Setup fixations -
ISO 5355-2006 (E). Alpine ski-boots - Requirements and test methods	F504-05. Standard Test Method for Measuring the Quasi - Static Release Moments of Alpine Ski Bindings	Recommendations on adjustment release levels
ISO 6004 - 1991. Alpine skis - Ski binding screws - Requirements	F939-06. Standard Practice for Selection of Release Torque Values for Alpine Ski Bindings	
ISO 6289-2003. Ski Vocabulary Technical Corrigendum 1	F1061-97/03 (re-approved). Specification for Ski Binding Test Devices	
ISO 8061-2004 (E). Alpine ski-bindings - Selection of release torque values	F1062-03. Standard Method for Verification of Ski Binding Test Devices	
ISO 8364-2007 (E). Alpine skis and bindings - Binding mounting area - Requirements and test methods	F 1063-03. Standard practice for Functional Inspections and Adjustments of Alpine	German - DIN 7881 D.  Winter sports equipment - Release bindings

ISO 9407 – Shoe sizes - Mondo point system of sizing and marking	Ski/ Binding / Boot Systems	for alpine downhill – skiing – Adjustment scale for release values
ISO 9462–2006 (E). Alpine ski-bindings – requirements and test methods	F 1064–03. Standard Practice for Sampling and Inspection of Complete and Incomplete Alpine Ski/ Binding / Boot Systems in Rental Applications	
ISO 9465–1991 (E). Alpine ski-bindings – Lateral release under impact loading – test method		
ISO 9838: 1991 (E). Alpine ski-bindings – Test soles for ski binding tests		
ISO 11087–2004. Alpine ski-bindings – Retention devices – requirements and test methods		
ISO 11088-2006 (E). Assembly, adjustment and inspection of an alpine ski/binding boot (S-B-B) system		
ISO 13993–2001. Rental ski shop practice Sampling and inspection of complete and incomplete alpine ski- binding–boot systems in rental applications		

Figure 5.3: Ski equipment standards.

Historical data contextualised the design stages, basis for safe set-up, and the limitations that exist in the current standards. Ski binding release recommendations, were established by the Internationale Arbeitskreis Sicherheit beim Skilauf (IAS) in 1970. The IAS was affiliated with the German standards institute, Deutsches Institut für Normung (DIN), and the German independent technical testing institute, TÜV. The equipment standards established by these groups provided the platform for the current standards. In most instances, the scope of each standard from different organisations on the same subject area differed only in layout and syntax. The International Standards Organisation (ISO) had clearer figures, tables and explanation of symbols whereas the American Society for Testing and Materials International (ASTM) contained more detail on the limitations of the scope of the standard. ASTM and national standards bodies cross-referenced to ISO standards when a particular aspect of equipment testing was not covered. Mounting, functionality of all three parts of the Ski-binding-boot system, and correct release settings were key to safety.

Mounting areas for bindings were specified in ISO 8364 and ASTM F473 (183, 184). A jig specific to the brand was required to mount the binding correctly. The mark on the left side or the top surface of the ski indicated the correct place for mounting the ski binding on the ski. Manufacturers of twin tip alpine skis used in freestyle manoeuvres specified the binding be mounted further forward than the position used for conventional recreational skis.

The effects of stiffness in ski-binding performance were tested using a torque-testing machine. Load combinations were applied to the toe-piece and the heelpiece. Technicians used weight, height boot sole length and skier type categories defined in ISO 9462 and ISO 11088 to determine the release reference point (185, 186). Torque wrenches provided an alternative testing method to machine torque testing. Further definition of the methods for selection of the release torques were specified in ISO 8061 and ASTM F 939 (187, 188) The release force equation was  $F_r = M / l$  (release torque in Newton metres  $M$  and the lever arm in metres  $l$ ). The number of recommended release tests of the binding in ISO 11088 (185) were up to 5 to the right, 5 to the left, and 5 in forward bending. Conversely, the number of tests prescribed in ISO 13993 (189) were a cycle of 3 tests in all directions. A deviation of more than 20% in twist and 15% in forward bending from

the reference values in either testing pattern resulted in a failed test. The mandatory information section on ski-binding test devices recommended all technicians complete manufacturer training (190).

Proper release from ski-bindings depended on the dimensions and design of the ski-boot sole, the ski-boot heel, a functional anti-friction device (AFD) and no impediment from the ski-brake mechanism. Tests ensured compatibility of the boot with the ski-binding and evenness of the weight bearing surface (191). ISO 5355 defined the lateral side walls of the sole at the boot heel; type A - adult boot 70 mm or a type C - child boot as 50 mm. Side walls at the boot toe needed to be perpendicular to bearing surface for at least 25 mm with an admissible deviation of 1mm in either an inward or outward direction. Cross-references were included to standards on the tensile and hardness properties of plastic. The radius of the boot shell at the heel was A  $35 + 6$  mm or  $- 2$  mm and C  $27 \pm 3$  mm. The front forefoot (described as area AB) and rear bearing surface of the boot (area CD) when in the binding was required to rest on the plane of the ski and not permit a 1 mm gauge to enter area AB or CD. The remainder of the boot sole should permit a gauge 10 mm in width to a maximum intrusion of 2 mm between the boot sole and ski. The exterior shell of the ski boot had a central mark on each side that lined up with the manufacturer mark on the ski and denoted the central placement position for the boot within the toe and heel of the binding.

Key rental ski shop practice steps covered in ISO 13993 and ASTM F 1064 combined information from the afore mentioned standards. Six safety and quality assurance steps were required. Firstly, undertake pre-season visual inspection and torque testing of all stock. This step included visual inspection, manual movement checks of the binding assembly and checks of the brakes and antifriction device. Torque-testing pre-season determined that a safe ski-binding release margin existed. The next two steps were boot inspection and cleaning. The fourth step outlined service requirements when the torque was  $\pm 15\%$  from the recommended reference point. In-season visual inspection prompted maintenance checks. Lastly, torque-testing a percentage of the rental stock during the season prompted further testing cycles (189).

ISO release values use tibial strength in torsion and bending data. Anthropometric and biomechanical data were first examined by Messerer over 100 years ago, followed by Outwater (1966, 1969), Vogel (1968), Asang (1970), Muller (1970) and Wittmann (1972) as cited by Pope et al (192). McMahan's work on the elasticity criteria for bones based on the relationship between the diameter and bone length was another important part of the tibial strength data. The normative ISO table (see Table 5.1) used the skier's weight, height and boot sole length to calculate release settings that had a safe margin from the predicted breaking point of the tibia. Multiple regression analysis predicting proximal tibial width informed the ISO normative release selection table. The second ISO table calculations for the optimum release setting used the actual skiers' tibial width as measured by callipers.

Table 5.1: Release value table adapted from ISO 11088:2006.

 Skier Weight <b>Pounds (kilos)</b>	 Skier Height <b>Ft. In. (cm)</b>	Skier Code	Toe and Heel Setting Indicator Value 					
			Boot Sole Length 					
			1	2	3 <sup>column</sup>	4	5	6
			≤ 250 mm	251 – 270 mm	271 – 290 mm	291 – 310 mm	311 – 330 mm	≥ 331 mm
<b>22 - 29 lbs.</b> 10 - 13 kg		<b>A</b>	0,75	0,75				
<b>30 - 38 lbs.</b> 14 - 17 kg		<b>B</b>	1	1	0,75			
<b>39 - 47 lbs.</b> 18 - 21 kg		<b>C</b>	1,25	1,25	1			
<b>48 - 56 lbs.</b> 22 - 25 kg		<b>D</b>	1,75	1,5	1,5			
<b>57 - 66 lbs.</b> 26 - 30 kg		<b>E</b>	2	2	1,75			
<b>67 - 78 lbs.</b> 31 - 35 kg		<b>F</b>	2,5	2,5	2,25	2	1,75	1,75
<b>79 - 91 lbs.</b> 36 - 41 kg		<b>G</b>		3	2,5	2,5	2,25	2
<b>92 - 107 lbs.</b> 42 - 48 kg	<b>4'10" or</b> 148	<b>H</b>		3,5	3	3	2,5	2,5
<b>108 - 125 lbs.</b> 49 - 57 kg	<b>4'11" - 5'1"</b> 149 - 157	<b>I</b>		4,25	4	3,5	3,25	3,25
<b>126 - 147 lbs.</b> 58 - 66 kg	<b>5'2" - 5'5"</b> 158 - 166	<b>J</b>		5	4,75	4,5	4	4
<b>148 - 174 lbs.</b> 67 - 78 kg	<b>5'6" - 5'10"</b> 167 - 178	<b>K</b>		6	5,5	5,25	5	4,75
<b>175 - 209 lbs.</b> 79 - 94 kg	<b>5'11" - 6'4"</b> 179 - 194	<b>L</b>		7	6,75	6,25	6	5,75
<b>210 + lbs.</b> 95 + kg	<b>6'5" +</b> 195 +	<b>M</b>		8,5	8	7,5	7	6,75
		<b>N</b>		10	9,5	9,0	8,5	8,25
		<b>O</b>		12	11,25	10,75	10,25	10

The skier type categories determined when corrections to the release value were required (for insertion in the skier code column in Table 5.1). Correction would result in  $\pm 0.5$  to 1.0 in the release setting. Standard definitions of skier type in the ISO and ASTM standards (92, 167) used three style levels (see Figure 5.4). Skiers who designated themselves as a Type 1 skier received lower than average release settings. Skiers who designated themselves as a Type 2 skier received average release settings appropriate for most recreational skiers. Skiers who designated themselves as a Type 3 skier received higher than average release settings. The Type 3 classification was not suitable for skiers 27 kg, and under.

Choose your Skiing Style 			
	Skier Type 1	Skier Type 2	Skier Type 3
Speed	Slow to moderate	Skiers that do not meet the descriptions of either 1 or 3	Fast
Terrain	Gentle to moderate		Steep
Style	Cautious (or undetermined)		Aggressive
Alternative			
Choose your Skiing Style 			
	Skier Type 1	Skier Type 2	Skier Type 3
	Cautious skiing on smooth slopes of gentle to moderate pitch	Skiers not classified as type 1 or type 2	Fast skiing on slopes of moderate to steep pitch

Figure 5.4: Three level skier type poster adapted from ISO and ASTM standards.

The French national organisation for standardisation Association Francaise de Normalisation (AFNOR) (92, 166) recommended five levels of description on skiing style, inclusion of gender in release calculations, and other at-risk groups (see Figure 5.5) . The at-risk groups identified were: poor physical condition, skiers of 7

days or less, women and light weight men (83). At risk groups, all received lower release settings than the normative value recommended by ISO.

 Choose your Skiing Style				
Skier Type -1	Skier Type 1	Skier Type 2	Skier Type 3	Skier Type 3+
Beginner less than 7 days of practice	Young beginner, with a poor physical condition	Good young skier, elastic and fluent style, all ski runs	Good skier aggressive skiing on all terrains	Excellent skier on dangerous abrupt slopes
	Intermediate level in poor condition <hr/> Good adult, flowing, fluid style, without aggressiveness, favouring safety	Coping level, good physical condition, but imperfect style, with frequent regain of balance	Frequent regaining of balance	Aggressive skiing on all runs with bad experience of the adjustment corresponding to type 3 (inadvertent release without necessity)

Figure 5.5: Five level skier type poster adapted from AFNOR.

Torque-testing machines had engraved boot sole length Mondopoint measurement bars with a curved bar for the heel. The boot sole measurement system was based on ISO 9407 shoe sizes - Mondopoint system of sizing and marking for alpine, telemark, and snowboard boots (193). The Mondopoint size represents the length of the foot in centimetres. For example, a size 29.0 ski boot

equals a foot measure of 29 cm. A Brannock Foot-Measuring Device supported ski technician accuracy with boot fitting.

Another equipment safety feature covered in the ISO standards was the ski-binding brake system; a compression spring mechanism triggered to unfold when the skier and the ski parted company. The ski-brake reduced the risk of injury to others from a loose ski becoming a dangerous projectile. ISO 11087 Alpine ski-bindings – retention devices – requirements and test methods (194) specified how the retention device should slow the run-away ski from every possible position on the slope regardless of snow conditions. ASTM had no specific standard for brake retention devices and cross-referenced to the ISO standard.

#### **5.1.6 Application and constraints**

Standards outlined the manufacturing advances in ski equipment made since 1970 and specified procedural steps to maintain quality. Most standards deferred to contacting the manufacturer for specific product information. The onus on technician education was not overtly the domain of any one party. Qualified ski technicians were essential for the operability of these ski equipment standards as gaps in technician education could lead to set-up error (89). ISO 8364 or ASTM F473 mounting standards did not consider do-it-yourself practices exacerbated by skiers buying equipment on-line. Skiers that mount ski bindings at home without a jig potentially could change the skier position and in-turn affect how a set of skis will manoeuvre. In the past ski technicians could replace internal parts of the ski-binding but in the current era repair is not always possible due to full encasement of some ski-bindings. However, the entire toe-piece, heelpiece, AFD, and ski brakes of most ski-binding brands when worn or damaged were replaceable. Replacing parts clearly has an associated cost that may present a barrier to some skiers immediately seeking repairs. Visual checks and torque testing provide ski areas with systematic opportunities to correct the deterioration of rental equipment that occurs after multiple use. Notably there were no standards on equipment maintenance procedures for skiers that owned ski equipment. ISO 13993 and ASTM F 1064 rental shop checklists could potentially be adapted for public equipment-related injury prevention messages.

To retain the skier in the ski binding the ski boot needs to be of an appropriate height at the toe and heel sidewall. When worn the boot will not interface correctly with the binding, thus creating the potential for inadvertent or premature release. Conversely, worn or dirty ski-boot soles with protrusions could increase friction and render the AFD device ineffective, locking the ski boot into the binding. Increased friction would likely change the pivot point and forces in lateral release (173). Ideally, the pivot point sits at the centre of the radius of the heel. Poor boot-fit could create unsafe situations during skiing. In particular, the pivot point and manoeuvres required for skiing may be affected if a person skis in an overly large boot. The take home message here is that ski boots are an essential interlinking part of the S-B-B system. Boot soles with excessive wear in the heel and toe (where possible) need replacing. Rental boots designed with no replaceable toe or heelpiece need to be withdrawn from service. A good boot-fit is part of the safety equation.

Using solely the skier's footwear size to determine the correct size without measuring the foot will increase the likelihood of the ski boot being an incorrect fit. Different sizing systems exist for street footwear, adding to the complexity of fitting ski boots. Confusion regards ski-boot sizing may arise when hiring. For example, Mondopoint 29.0 correlates to street shoe sizing UK 10.5, US 11, and Euro 45. The conversion formula to convert the Mondopoint to US footwear sizing was  $2 + 9 + 0 = 11$ . For large rental operations ensuring a comfortable boot fit that enhances skiing style may be a level of service that is marginalised by the pressures to get numbers through the rental facility and out on to the slopes (89). Good ski-boot fitting requires time. Unlike the comfortable tennis shoe with space for the foot to move forward, the ski boot requires a snug fit with the toe touching the end of the boot. When buckled the heel needs to be flush with the rear of the boot, the buckling also moves the toes off the end of the boot. Foot pronation and knee angles create further complexity for ski technicians that have limited boot-fitting education.

Compatible ski boots and functional ski-bindings create a safety retention and release system. The physical parameters of the skier are required for individualising the S-B-B system. The elasticity threshold of bone results accounted for in release settings set lower than breaking point of the tibia (192, 195). Proximal tibial width measurements were the best predictor of strength of the tibia. However, calliper measurement of the proximal tibial width were difficult as fatty tissue levels of the

two curving surfaces varied markedly in thickness (83). Orthopaedic surgeons were unable to measure proximal width accurately, raising concerns that ski technicians with less anthropometrical training would not be able to make an accurate measurement. Of concern is that overestimating proximal tibial width could more than double the predicted strength of the tibia shaft (192). Incorrect release values may expose the skier to injurious moments (48, 83). Despite accuracy concerns, the proximal tibia width method for calculating S-S-B release values remains in use (mostly in Europe). Curiously, previous researchers have observed that height, weight, and wrist circumference were better predictors of actual proximal tibia width than the measured tibia width (178, 196). The two factors to balance with ski binding release settings were to ensure that the skier stays in the binding in normal skiing manoeuvres and ensure that the skier releases from the binding in manoeuvres that may result in injury. The range for the acceptable torque values at the toe and heelpiece of  $\pm 15\%$  from the reference point for the release setting was relatively wide. Also of note is that the addition of release possibilities in the multi-directional ski binding are not considered in the release tables.

The torque parameters used in the current standards centre only on S-B-B systems reducing lower leg fractures. The pivot point of the heel is behind the projected tibia axis resulting in ski-bindings sensing loads at the front of the ski rather than the back (173). The snow surface may increase or decrease friction, altering the external forces at play. There were polarised viewpoints on how much knee protection the present S-B-B system could offer. In posterior knee injury mechanisms there was no load on the dual directional or multi-directional binding to trigger release, so no protection (70, 82, 88). However, in anterior mechanisms where knee injury occurred, the binding mechanism was loaded and when set correctly the binding could release and provide knee protection (48, 49, 83, 172, 197, 198). Examination of critical loads resulting in knee injuries have been examined in cadavers, computer simulation, case studies, and in 3D video analysis of falling ski racers. Mixed-methods research contribution to advancing understandings of where correctly set-up modern ski-bindings can offer protection is best described as a work-in-progress (172, 197-203).

Female skiers rupture the anterior cruciate ligament 2 to 3 times more often than male skiers (204). This higher incidence of knee injury in females has occurred

in the context of ISO torque values that do not account for gender (48). Female skiers on carving skis that had not had recent ski-binding adjustments were particularly vulnerable to knee injury. The permissible forces in the ISO release value table were found to be far greater than the forces required to ski normally (196). Laporte et al. concluded, “there is no objective risk involved in promoting a reduction in settings for women, especially beginners. It is possible to reduce ski bindings (settings) because there is a large potential action reserve. The risk of inadvertent release is perfectly acceptable in the majority of cases envisaged” (p. 106) (48). The French standards body AFNOR moved away from the ISO standard fifteen years ago and reduced release values for women by 15%. To-date AFNOR FD S 52-748 (205) has not replaced the ISO release value selection table that uses the skiers weight table (185). This inertia is perplexing given the prevalence of knee injury in skiers and the known at-risk groups. Given the wide margin of acceptable deviation from the reference value of  $\pm 15\%$  there is latitude to lower the settings. Much of the delay to lower the release settings appears to be based on the view of some standards committee researchers’ view that the ski-binding cannot provide protection for the knee in any direction. The solution proffered by Vermont Ski Safety to reduce Anterior Cruciate Ligament ruptures was to educate skiers on how to fall (69, 83, 85). The do not attempt to stay upright and stay down education intervention has predominantly been used with ski area employees and resulted in reduction of knee injuries. AFNOR also recommended a reduction of the release setting of 15% for men below 49 kg and 5% for men 49–57 kg. For men over 57 kg no change was recommended. The practical implication of a 15% reduction was selecting a release setting one line down on the ISO 11088 release value selection table (83).

Additional adjustments made in release value selection were based on skier’s self-selected skiing style. The ISO and ASTM descriptors (see Figure 5.4) used by skiers to make these decisions were closely associated to ability; however, to reduce ambiguity the text did not use the terms beginner, novice, intermediate, advanced or expert. The lack of description for the type two skier in the ISO and ASTM poster recommendations was concerning as overstating information supplied on individual skiing style could lead to the release setting being too tight (206). Skiers require a basic understanding of ski binding adjustment to make an informed decision on

acceptable risk. When comparing the AFNOR chart with the text in the ISO chart skiing style descriptions were more detailed and possibly easier to determine.

Alongside research related to safe set-up of the S-B-B systems, equipment design solutions will eventually expand international standards. Greater degrees of freedom in the binding movement pattern and reduction of the constraining forces of the ski binding with sliding elements and bearings may present the answer for knee injury reduction. An update of ISO 9465 and improvement of the dynamic behaviour of the heel table for action as the present standard only covers the toe-piece. Mechatronics that monitor and control the function of the ski-binding and electronic components that identify strains between the boot and the ski-binding that trigger release are also back on the design agenda.

### **5.1.7 Conclusion**

Equipment choice denotes a greater or lesser degree of risk. Alter one design parameter and it is likely that another parameter is affected. For the individual skier, equipment design advancements may not necessarily mean compatibility with skiing style. Published standards provide transparency on testing and support quality. Biomechanical scrutiny that includes a range of skiing styles, abilities and physical parameters may not have been considered by the manufacturer. Independent testing using international standards as the basis of equipment selection for a cross-section of the recreational skiing population could reduce the influence of brand marketing. The multi-direction binding provides a good example of the gap between engineering advances and writing standards with potential consequences, the release tables may not be suited to the elastic toe-piece movement as the calculations only considered two directions ( $M_z$  and  $M_y$ ). The prospect of an intelligent mechatronic ski binding that detects potential for injury and triggers release is exciting but not yet on the market. In the first instance, age of ski binding influence on release capabilities needs to be examined.

The existing standards provided comprehensive information for maintaining quality equipment. However, to be effective standards need enacting on a daily basis. Of concern was that no standard existed on routine maintenance practices for skiers that owned equipment. Rental operations standards recommended

regular torque testing; logically this type of equipment testing practice should also apply to privately owned equipment. The ski boot needs to engage with the binding and checks are needed to ensure the AFD is effective and that there are no impediments to release. Annual checks of the release calculation are paramount as a skier's weight may change between seasons. Increasing snow sports participants understanding of safe equipment set-up, clearly is warranted. Skiing style may also change from season to season. Aggressive and fast skiers need ski-bindings with settings that can account for exposure to higher kinetic forces. Skiers that have a skiing style that adapts to snow conditions and terrains by varying their speeds, warrants lower release settings. The higher proportion of female knee injured skiers clearly is of concern for the sport. The more descriptive AFNOR release table considered at-risk groups when determining release settings. Accounting for gender when determining the release setting warrants further investigation.

## **Part 2: Evaluation of ski-binding-boot system safety using torque-testing**

### **5.2.1 Introduction**

Ski-bindings are constructed using levers and springs. Calibration procedures ensure that the binding mechanism works effectively, and that the release value indicator is truly reflective of the torques or force required for the ski binding to release. To accurately set-up alpine ski-binding-boot (S-B-B) systems there are trade-offs between a maximum retention setting likely to cause injury due to non-release and, conversely, a minimum retention setting likely to cause injury due to inadvertent release, and a more appropriate ski-binding release value that is easy to calculate in a busy ski hire setting (178). It is not possible to ascertain the exact status of the S-B-B system without making torque checks using a calibration device. Currently in New Zealand there are no major ski areas using calibration machines to test their rental fleets; only two off-hill ski rental businesses use a calibration machine, and only one of these businesses pre-season tests all of their rental fleet. There are no rental outlets in New Zealand using torque wrenches. International standards produced by ASTM International and ISO (90-92) outline the necessity to use torque-testing equipment to accurately determine the S-B-B system functionality. Large rental outlets in New Zealand replace ski rental equipment on a three-year to four-year cycle. There are no replacement cycle recommendations in the standards. Skiers that own skis in New Zealand have limited access to torque-

testing equipment. There is no national education programme for alpine skiers on the necessity to correctly set-up and torque test alpine ski equipment. The exact number of countries that consistently apply international standards for set-up and testing of alpine ski equipment is not known. Medicines de Montagne reported that although skiing is popular in France, understanding and adoption of equipment-related practice standards in France is limited (83).

Current research findings on equipment-related injury were provided to the national ski areas association from an epidemiological study on the magnitude of the lower limb injury problem in alpine skiing in New Zealand using Accident Compensation Commission (ACC) snow sports injury claimant data 2000 to 2007(207), and from a prospective study on current rental shop practices using surveys in 2008 and 2009(207, 208). After the survey results were presented national ski areas association members requested more evidence as to why they should purchase calibration machines or torque wrenches rather than continuing to use their present maintenance and rental fleet replacement strategies. The purpose of this study was to provide more data to support the introduction of a uniform method of testing and maintaining alpine ski equipment.

### **5.2.2 Methods**

The study involved testing alpine S-B-B systems to determine the release torque and percentage of alpine S-B-B systems that did not meet the international standard for release torque. Testing parameters were based on a 70 kg skier aged less than 50 years, 1.70 m height, type II skier ability and a ski boot that was 314 mm in sole length that warranted a release value of 6.0 as outlined in ASTM F939-06(167) and ISO 11088:2006 (E)(92) release value tables. The reference moment as calculated using the international standards release tables for these skier parameters were 224 Nm in My (forward lean in the heel) and 57 Nm in Mz (twist right, i.e. clockwise; and twist left, i.e. anticlockwise in the toe-piece). The in-tolerance threshold was  $\pm 15\%$  from the reference moment. Deviations from the tolerance threshold were Class I deviations when the S-B-B toe-piece and/or heelpiece were  $\pm 16\%$  to  $\pm 30\%$ , Class II  $\pm 30\%$  to  $\pm 45\%$ , or Class III deviations when the S-B-B toe-piece or heelpiece test result was more than  $\pm 45\%$  Three trials for each S-B-B system for forward lean or twist direction were recorded. Comparisons between trials were calculated. The

proportion of the S-B-B that did not meet the threshold of  $\pm 15\%$  was determined to not be in tolerance. Logistic regression analyses were used to determine the effect of age (seasons of use) on binding release using the third trial.

### **5.2.3 Sample characteristics**

Random sampling was conducted of the ski rental fleet at the sole rental shop at one commercial ski area. Every ski with a mounted binding had an equal chance of being included in the sample. The ski area manager stated that the total inventory was 700 pairs of skis. ASTM and ISO guidelines for random sampling are 5% of the rental fleet. The researcher randomly selected 16 pairs of skis from year one, 16 pairs of skis from year two and 16 pairs of skis from year three ( $n = 48$  pairs). There were only 14 pairs of four-year old skis in the rental fleet so all 14 pairs were tested. There were two brands of S-B-B with one season of use (Brand A and Brand B). The older rental fleet were all Brand (B) systems. A total of 62 pairs of S-B-B were tested ( $n = 124$  skis).

### **5.2.4 Equipment and procedures**

The Wintersteiger calibration machine determined the force (torque) required to release the boot from the ski binding and whether or not the ski binding release value indicator was accurate (see Figure 5.5). The calibration machine was moved from the resort town of Queenstown to the ski area, a distance of 18 km (11 miles). As movement can affect the accuracy of the torque-testing machine, checks of the machine were made with the manufacturer's calibration device prior to commencing S-B-B testing. Five adjustments of the machine were required and conducted as per the manufacturer's manual before testing began. For reliability, rechecks of the machine were made with the calibration device after each set of 30 tests; no further calibration of the machine was required.

A single ski boot from the rental fleet with one season of use and no wear and tear on the sole was used as the reference boot to test the entire rental fleet. A reference boot is a boot that is compatible with the ski binding that has no excess wear on the heel and toe-piece and is typical of ski boots that are in the inventory

(see Figure 5.6). The boot was checked after each test to ensure that there were no contaminants that could lead to boot/binding incompatibility.



Figure 5.6: Wintersteiger machine torque testing the toe-piece in Mz twist.

### 5.2.5 Results

All S-B-B systems that were found to be more than 15% from the reference moment were over tolerance (too tight). No S-B-B systems tested were under tolerance (too loose). The rental fleet inventory failed the in-season inspection as more than 20% of the sample torque-tested had Class I deviations. Class II deviations of 48% were found in S-B-B with two seasons of use. Of the rental fleet 3% with two seasons use and 5% of the rental fleet with three seasons use had Class III deviations (see Table 5.2).

Table 5.2: Proportions as percentage of SBB systems in classes of deviation from the reference release moment.

Seasons of use				
	One (n=32)	Two (n=32)	Three (n=32)	Four (n=28)
Heelpiece over				
Class I	9.5	50.0	95.0	63.6
Class II	0	47.5	0	0
Class III	0	2.5	0	0
R) toe-piece over				
Class I	23.8	42.5	25	54.6
Class II	0	0	0	9.1
L) toe-piece over				
Class I	81	67.5	65	90.9
Class II	4.8	0	15	4.6
Class III	0	0	5	0

Classes of deviation are defined as the following changes in moment that are required to release the boot from the ski binding. Torque test results that are more than 15% under or over the reference release moment. Class I  $\pm 16\%$  to  $\pm 30\%$ , Class II  $\pm 30\%$  to  $\pm 45\%$ , Class III  $>\pm 45\%$ .

In further analysis of Table 5.2, the heelpiece of older S-B-B was nine times more likely to be out of tolerance than those after one seasons use (proportion ratio 9.4, 90% CI 7.8 to 10.1)<sup>3</sup>. However, there was only a small increase in the proportion of toe-pieces out of tolerance for older compared to the newer S-B-B systems (proportion ratio 1.12, 0.92 to 1.31). Two manufacturers S-B-B systems (Brand A and Brand B) were used in the newer rental fleet with one season of use (see Table 5.3). Only Brand B systems were used in the older rental fleet that had two to four seasons of use.

<sup>3</sup> Magnitude-based inferences (133) provide an informative approach on the quantitative chances (%) that the true value is harmful, trivial or beneficial (non-clinical outcome statistics are examined with a 90% CI and clinical outcomes, a 99% CI).

Table 5.3: Proportions (%) of each of two brands of S-B-B systems tested that had one seasons use showing Class I and Class II deviations from the reference moment for release.

	Brand A (n=16)	Brand B (n=16)
Heelpiece over		
Class I	7	0
Class II	0	0
R) Toe-piece over		
Class I	0	19
Class II	4.8	0
L) Toe-piece over		
Class I	38	43
Class II	4.8	0

Only Brand B were in the rental fleet for seasons two to four

### 5.2.6 Discussion

Ettlinger, Johnson and Shealy (88) in a study of the functional and release characteristics of alpine skiing equipment in a case-control study of 17,967 injuries over 32 years (1972 to 2004) noted that “the problem, in the opinion of the authors, is not the standards, but their implementation...Skiers who shun the efforts of a well-trained mechanic in a properly equipped ski shop and instead put blind faith in their binding’s release indicator are not well served”(p.71). Calibration machines and torque wrenches determine release torque values and the accuracy of the release value indicator. Manual twist of the toe-piece by the ski mechanic or skier, or manual release in the heelpiece does not prove that the ski-binding release setting (DIN) is actually working at the torque level registered on the scale at the binding toe-piece and/or at the binding heelpiece. There was a high percentage of Class I deviations in the rental fleet that was tested; 50% (2 seasons), 95% (3 seasons), 64% (4 seasons). Latitude exists in tolerance from the reference moment in Class I  $\pm 16\%$  to  $\pm 30\%$ . Torque values in Class I are classified as a minor deviation not requiring correction. As outlined in ASTM 1064-03(91) and ISO 13993:2001(90) where a class I deviation of 20% is detected, the inventory fails and the entire rental fleet should be inspected. With Class II deviations of 48% that had two seasons of use, the reliance on retiring ski rental equipment on a three-

season to four-season basis to ensure that safe equipment is supplied can be questioned. Incorrect release settings may result in S-B-B systems that are too tight or too loose. Class II deviations of  $\pm 30\%$  to  $\pm 45\%$  prompt inspection of the entire inventory, and maintenance; where maintenance does not remedy the Class II deviations correction is required during set-up. The correction requires factoring the deviation into the determination of release value setting as determined by skier weight, height, boot sole length; the correction is three lines up or down from the selected reference moment. Only 8% of the rental fleet had Class III deviation of greater than  $\pm 45\%$  indicating that these skis should be removed from the inventory.

To gauge the workload implications for busy ski rental operations, one Class II S-B-B system of the tested rental fleet (n=124) was manually adjusted. The ski-binding release value indicator had to be adjusted down three times to get within the permissible range resulting in a release setting on the heelpiece of 4.5. The total time for this adjustment process was 10 minutes. An automated machine ensures testing time would be reasonably fast; however, when equipment adjustments are needed there would be an impact on customer clearance through the ski rental shop.

Torque-testing results from the commercial ski area were compared with release torque-testing paper-based records for 2009 for Browns Ski Shop in Queenstown(209). The historical data identified that there were 790 tests with only 5.4% (n= 43) Class I deviations. These data support the benefits of a long-term torque-testing programme in determining maintenance and rental fleet replacement requirements. A system also needs to be set up for ski rental workers to identify S-B-B with Class II deviations. For example, Browns Ski Shop use waterproof colour coded identification on the ski tip to alert the ski rental worker that the deviation needs to be factored in when setting the release value indicator; this system may not be suitable for commercial ski area rental shops.

### **5.2.7 Limitations**

A possible limitation in the study is that there was insufficient four-year old stock to randomise. Another possible limitation was that there were three different ski-bindings in the Brand B rental fleet. Based on product information, there were

apparently no changes to the rental ski-binding mechanism from this manufacturer over the years of purchase of the rental fleet (2005 to 2009), the changes to Brand B were only cosmetic. However, if there were any changes in the rental ski-binding mechanism this might impact on the performance of the ski binding and the findings on the effect of years of use. Regardless of the cause, the high proportion of S-B-B systems out of tolerance is an important equipment safety concern.

### **5.2.8 Practical recommendations**

Torque-testing S-B-B using a calibration machine or torque wrench is essential to ensure that the whole mechanism is working effectively, and that the release value indicator is truly reflective of the forces (torque) that are required for the skier to release from the ski binding. Although there has been extensive work by ski researchers and standards organisations to determine the appropriate set-up and maintenance of alpine skiing equipment, there appear to be disconnects with practitioners.

According to ASTM F1064-03(91) and ISO 13993: 2001(90) pre-season visual inspection and manual movement checks of the S-B-B system are required. This manual manoeuvre only tests elastic travel and recentering; it does not replace the need for torque testing. Boot inspection is also needed to determine whether the boot sole is worn and remains compatible with the ski binding. Cleaning and servicing to remedy any issues of wear and tear including ski-edge maintenance, ski-base repairs, and waxing are paramount for performance and equipment safety. Alpine skiers who own their own equipment need to undertake the same regular routine inspection of equipment and functional torque testing as rental shops to ensure that they too are skiing on safe functional equipment that will release under the appropriate load. All skiers, whether on rental or private equipment, need to have equipment that is set up accurately for their age, weight, height, boot sole length and skier type.

It is recommended that all rental shops apply standards of inspection and torque testing of S-B-B systems pre-season and in-season to mitigate the risk of equipment-related injuries. It is also recommended that alpine skiers who own their equipment be provided with information on correct set-up, maintenance and

testing. Finally, easy access to torque testing for all skiers should be provided across New Zealand and in any other countries lacking adequate torque-testing services.

## CHAPTER 6 – RISK REDUCTION

### Prelude

In Chapter 4, it was established that the use of torque machines or torque wrenches to ensure safe set-up of ski-bindings, was rare in New Zealand, despite international recommendations. From the analysis in Chapter 5, it was found that age or seasons of use influenced ski-binding function. Regardless of the age of the binding mechanism and maintenance history, skiers seemingly put blind faith in the ski-binding release capabilities. Manual self-release tests promoted in early research and the popular press were an alternative safety ski-binding check to machine torque testing. However, it was unknown whether in the absence of torque testing the self-release test was a suitable safety check for recreational skiers of any ability. This chapter, actions TRIPP Stage 4 by assessing the proposed intervention in the ideal controlled conditions of an indoor snow dome. The status of privately owned ski equipment adds to the ski equipment causation data presented in earlier chapters.

## Can skiers establish safe ski binding release torques using a self-release manoeuvre?

### 6.1 Introduction

To prevent injury to the knee or lower leg, skiers need to have ski-bindings that function effectively, are correctly set-up for the individual, and release under critical loads. Orthopaedic surgeons had recommended that skiers should perform a self-release test prior to commencing skiing each day to prevent such injuries (86, 210, 211). The self-release test purportedly determined that the ski binding boot (S-B-B) system was safe; however, the stationary manoeuvre to release the S-B-B has had limited empirical testing (86). Overly tight release settings were one of the factors attributed to the high incidence of knee injuries in alpine skiing (49, 67, 77). Over a third of all skiing injuries involved the knee and for female skiers injury to the knee was 2 to 3 times more likely than males. Also of concern was that the decrease in fractures of the tibia initially seen with the release binding has not been sustained (8, 47). Injury statistics provided a red flag that incorrect binding settings and function were a key factor in injury. Finding interventions that could help injury reduction of the knee and lower leg would seem paramount.

There was a paucity of literature on the stationary self-release manoeuvre with only one experimental study by Werner and Willis in 2002 (86). Promotion of the self-release manoeuvre existed in earlier data with no empirical testing (210-213). No studies analysed skier self-adjustment practices. Screwdrivers attached to ski racks at most ski areas or lift buildings indicated that adjustment of the binding potentially is a common practice (see Figure 6.1). However, ski area messaging to tighten the screws, could potentially result in skiers setting higher than ISO recommended torques and increasing the risk of injury (83).



Figure 6.1: Screwdrivers provided for self- adjustment.

In terms of torque testing, muscularly strong skiers could perform the self-release manoeuvre at the recommended torque (86). For example, reference torques for a 67 to 78 kg skier, height 167-178cm were 50 Nm (newton metres) in Mz (twist) and 194 Nm in My (forward lean) (167). A release setting ( $z = 6.0$ ) was determined from torque formulae for the toe-piece and heelpiece (92, 214). Further adjustments were made to the release setting based on skier type (skiing style) and age. Binding release occurred when all loads to the ski boot-binding connection have reached zero and presented no further danger. Nineteen skiers could self-release (86), concerning was two skiers could self-release at settings higher than the recommended setting which may have increased the risk of leg injury. Potentially the self-release manoeuvre was simply a strength test rather than a safety test. A further limitation of this study was the small sample size making generalisability questionable ( $n = 25$ ; 10-14yrs (5) - 80% male; 20 - 63yrs (20) - 56% male).

To the knowledge of these authors' no researchers have examined recreational skiers' capacity to perform the self-release manoeuvre on privately owned ski equipment set for/by the skier. Furthermore, the capability of individual skiers to select and make adjustments that have parity with International Standards Organisation (ISO) recommended release setting has not been examined. Given the preceding information, the purpose of this study was to determine whether the self-release test was a valid alternate to machine torque testing for assuring safe ski binding release torques in recreational skiers of any ability.

## 6.2 Methods

### Subjects

Recreational skiers who owned ski equipment were invited to participate in an experimental self-release study at the indoor snow dome in Auckland, New Zealand in the two months prior to the winter season of 2015. Recruitment strategies included: invites to the indoor snowdome Facebook mailing list, ski club newsletters, wall posters placed at all ski retailers in the Auckland area, and email invites to university faculty. Participants were incentivised with free torque testing and with free skiing. To ensure skiers of all abilities were included in the study, novices on rental ski equipment were able to participate. Exclusion criteria were skiers suffering an acute leg injury in the last 3 months. The study protocol and informed consent and assent forms approved for skiers aged 14 years and over (no upper age limit), Auckland University of Technology ethics committee #1453 (see, Appendix I and VII).

### Testing schedule

After written informed consent was received, demographic data were collected on age, gender and leg injury history. Physical attributes were determined using electronic scales for weight (SECA model 876), stadiometer (SECA model 213) for height, and the ski-binding adjustment device (Montana Jetbond M) for calculating boot sole length. Leg dominance was determined using questions from the revised Waterloo Footedness Questionnaire (215). All participants were asked, “Which foot do you use to kick a stationary ball at a target straight in front of you?” For those that could not identify with the first question an additional question used “if you had to hop on one foot which foot would you use?” Self-selection of skier type was determined using the International Standards Organisation (ISO) three level skier type chart (92) (see, Appendix VIII ). Type I self-identified with a cautious skiing style at slow to moderate to slow speed on gentle to moderate terrain. All terrain skiers that declared adaption of speed and style to the degree of difficulty classified as

Type II. Skiers that self-identified with an aggressive skiing style at speed on steep terrain classified as Skier Type III.

Skier equipment details gathered on age of the ski equipment, the last time the ski equipment was machine torque tested, and days skied in the last calendar year.

Machine torque testing occurred in the airlock space between the rental area and the snow dome. The machine secured to a wall to ensure the machine could not move and a safety zone established with barriers to protect onlookers. Spirit level checks ensured that the ski was on a flat table surface during testing. Accuracy checks automatically occurred when the machine switched on. To confirm the automatic system findings, a manual test with a reference ski and boot was performed each day.

Three subjective descriptions of wear and tear were used to determine ski boot compatibility: 1 – minimal, scuffed boot-sole, compatible; 2 – moderate, spalled or pitted boot-sole, compatible but wear and tear may alter surface friction during release; and, 3 – extreme, sole and side wall height not per international standards specifications, eroded surfaces may disengage during skiing, not compatible (168). A check of the anti-friction device on both skis was also undertaken.

Participant weight, height, age length of boot sole and skier type entered into the data field on the machine touch screen (see Figure 6.2) and the nominal torque for the skier was calculated. One ski was clamped into the machine and one ski boot engaged with the ski binding using a leg simulator on a swivel arm. The screen displayed the nominal value or ideal value in Nm with upper and lower tolerance limits in Nm. The nominal value to set the binding release scale parts (z) displayed on the screen and recorded on the print out (for example, 6.5 z). Validity of the criterion release setting has been deemed the gold-standard by the International Standards Organisation (152). The machine once activated applied a twisting force to the ski binding of a single ski to the left, right, and forward lean for a maximum of five tests in each direction. The procedure repeated with the second ski-binding-boot system for a maximum of five tests in each direction. Nominal and actual

torque measures were recorded in machine printouts and data collection forms. There were no adjustments made to the release setting on either ski when the S-B-B was under or over tolerance.



Figure 6.2: Torque testing machine.

Skiers viewed a demonstration video by the snow dome Canadian Ski Instructors' Alliance level three instructor. Performance tests occurred on a flat area of hard pack snow at the base of the lift in minus 2 degrees Celsius. The researcher in accordance with the manufacturer recommendations provided self-adjustment instructions on the snow. Both ski poles used for balance and the ski placed on the inner edge. As per the test method used by Werner and Willis (2002) skiers performed a forced inward twist of the foot and leg to open the toe-piece of the ski-binding of both skis (86). Skiers that were unable to self-release used a screwdriver to adjust the ski-binding release indicator down by 1.0 on the release indicator of the toe-piece of the binding. After adjusting the toe-piece, the skier re-attempted self-release. No adjustments were made to the heelpiece. This procedure was repeated a maximum of three times. Skiers could opt out of performing a self-release manoeuvre at any point if they were physically unable and/or expressed concern that they were creating excessive stress on the ankle or knee joint. Skiers returned to the warm testing area and a repeat S-B-B torque-test determined the torque setting that allowed self-release.

### Statistical analysis

Proportions of skiers who could self-release were analysed with the logistic-regression version of the generalized linear model (Proc Glimmix) in the Statistical Analysis System (Version 9.4, SAS Institute, Cary, NC), with allowance for over dispersion. Separate analyses were performed for the modifying effects of gender (female, male); age (14-19, 20-39, 40-59, 60-81); leg dominance (right, left); days skied in previous calendar year (7 days or less, 28 days or less, > 28 days); previous knee or lower-leg injury (no, yes); and skier type (I, II, III). Similar analyses were performed for age of ski-bindings (0-1, 2-3, 4+ years); ski boot wear (grade 1, 2, 3); and the proportion of ski-bindings that were under or over the 15% and 30% tolerance limit used in ISO standard 11088 (152). Effects relating to equipment status were assessed with non-clinical magnitude based inferences, whereby effects were deemed clear and their magnitudes interpreted when the 90% confidence interval did not include substantial positive and negative values (216). Effects relating to the self-release/self-adjustment intervention were assessed with clinical magnitude-base inferences, whereby potentially beneficial effects (probability of benefit >25%) were declared clear if odds of benefit outweighed odds of harm by >66 %.

### 6.3 Results

subject (n=157) characteristics were, 115 male and 42 female (age: 45 ± 18 years; height: 173 ± 13cm; weight 78 ± 13 kg). Footedness: 95% right leg dominant. Previous injury to knee or/and lower leg: never 39%, skiing 32%, other activity 21%, combined skiing and other activity 8%. Of those injured skiing: knee 67%; lower leg 24%; combined knee and lower leg 9%. Injured in other activity: knee 53%, lower leg 31%, combined 16%. All subjects with a history of injury in other activity had sustained injuries to both the knee and lower leg. Of the 157 recreational skiers 10% self-identified as Skier Type I, 42% Skier Type II, and 48% Skier Type III. ISO 11088 Class I deviation 15% from the reference point were determined when the S-B-B toe-piece were ±16% to ± 30% (see, Table 6.1).

Table 6.1. Equipment status - modifying effects of skier characteristics and equipment age on binding tolerance at 15% level.

	Over-tolerance (%)	Comparisons
<b>Gender</b>		
Female	30.4	F/M 1.0, 0.71 - 1.36
Male	30.2	
<b>Skier Type (T)</b>		
TI	13.8	T2/T1 2.42, 1.18-4.08; ↑***
TII	33.3	T3/T1 2.24; 1.08 -3.88; ↑***
TIII	30.9	T3/T2 0.93; 0.67-1.23
<b>Binding Age (yrs.)</b>		
A 0-1	34.3	A/B 1.72, 1.19-2.33; ↑**
B 2-4	20	A/C 0.80, 0.55-1.10; ↓*
C 5-18	42.9	B/C 0.47, 0.30-0.70; ↓***
<b>Boot Wear</b>		
1 Minimal	33.2	1/2 1.31, 0.93 - 1.75; ↑*
2 Moderate	25.3	1/3 2.32, 0.53-2.32
3 Extreme	14.3	
<b>Key:</b>		
	<b>Skier Type (T)</b>	
TI	Cautious, gentle to moderate terrain, slow to moderate speed	
TII	Does not meet skiing style description of either I or III, adapts speed to conditions	
TIII	Aggressive, steep terrain, fast	
	<b>Boot Wear Grading</b>	
1	Minimal - scuffed boot-sole, compatible	
2	Moderate- spalled or pitted boot-sole, compatible	
3	Extreme, eroded surfaces, sole and sidewall height not per international standards specifications, not compatible	
	<b>Comparisons</b>	
Effects clear at the non-clinical 90% level and likelihood that the true magnitude when effect is positive ↑, negative ↓, *small, **moderate, *** large		

All Type I novice skiers were on new rental equipment purchased in 2015. Type II and Type III skiers mostly owned equipment (97%), the remainder borrowed new rental skis. Ski-binding-boot system age: 3 years  $\pm$  3 years; age of boots 4 years  $\pm$  4 years. No private or rental skis had ever had release settings determined with machine torque testing.

There was no significant effect of gender on binding being over tolerance in initial testing of binding status (equipment baseline test before on snow self-release) at the 15% level (see Table 6.1). This also applied at the ISO 30% level or Class II deviation ( $\pm$  30% to  $\pm$  45% from the reference point).

When comparing skier type there was a clear effect for both Skier Type II and Skier Type III for over tolerance at the 15% and 30% level (see Table 6.1 and 6.2). Skier Type 1 equipment was not over tolerance at either level. There was also a clear effect of ski-binding age on torque (see Table 6.1 and 6.2). New S-B-B with up to 1 year of use was more often 15 to 30% over tolerance than S-B-B of 2 to 4 years use. Conversely, older bindings of 5 to 18 years were more commonly 15 to 30% under the recommended torque (see Table 6.1 and Table 6.2). The effect of boot wear was minimal at 15% and non-significant at 30% (see Table 6.1 and 6.2).

Table 6.2. Equipment status - modifying effects of skier characteristics and equipment age on binding tolerance at 30% level.

<b>Over-tolerance</b>		
	<b>(%)</b>	<b>Comparisons</b>
<b>Gender</b>		
Female		F/M 0.85, 0.53-1.31
Male		
<b>Skier Type (T)</b>		
TI	6.9	T2/T1 3.34, 1.13-7.46; ↑****
TII	23.0	T3/T1 2.29; 0.072-5.83; ↑***
TIII	15.8	T3/T2 0.69; 0.44-1.05
<b>Binding Age</b>		
A 0-1	21.2	A/B 1.66, 1.00-2.58; ↑**
B 2-4	12.8	A/C 0.93, 0.55-1.46
C 5-18	22.9	B/C 0.56, 0.31-0.96; ↓**
<b>Boot Wear</b>		
1 Minimal	18.4	1/2 1.04, 0.65-1.60
2 Moderate	17.6	1/3 1.29, 0.25-4.07
3 Extreme	14.3	

**Key:** **Skier Type (T)**  
 TI Cautious, gentle to moderate terrain, slow to moderate speed  
 TII Does not meet skiing style description of either I or III, adapts speed to conditions  
 TIII Aggressive, steep terrain, fast  
**Boot Wear Grading**  
 1 Minimal - scuffed boot-sole, compatible  
 2 Moderate- spalled or pitted boot-sole, compatible  
 3 Extreme, eroded surfaces, sole and sidewall height not per international standards specifications, not compatible  
**Comparisons**  
 Effects clear at the non-clinical 90% level and likelihood that the true magnitude when effect is positive ↑, negative ↓, \*small, \*\*moderate, \*\*\* large

The median number of ski days was 17 with those skiers skiing 0-7 day the mean was 1.9 STD ±2.2; 8-28 days 14.6 ±5.9; >28 days 69.6 ±45.4. There was no effect of number of days' skied on self-release ability (0-7 vs. 8 – 28 days, 1.37; 8- 28 vs. > 28 days, 0.94). Regardless of release settings, Type III skiers were more likely to be able to perform a self-release than both Skier Type II and Skier Type I (see Table 6.3). Skiers aged 14 – 19 years were less likely to perform the self-release manoeuvre when compared to adult skiers.

The effect of leg dominance on self-release was unclear. Gender did not predict self-release in the first attempt. A previous knee or lower leg injury did not limit self-release in the first attempt. Of those that self-released only 28% self-released on ISO recommended release torques, all other skiers could only release when the ski-binding settings were lighter than recommended (see Table 6.3).

Table 6.3: Modifying effects of subject characteristics in first self-release.

	Successful (%)	Comparisons
<b>Gender</b>		
Male	46.3	
Female	42.2	M/F 1.10, 0.75-1.46
<b>Age*</b>		
A 14 – 19	9.5	A/B 0.31, 0.15-0.97; ↓**
B 20 - 39	31	A/C 0.30, 0.15-0.88; ↓**
C 30 - 59	31	A/D 0.21, 0.12-0.55; ↓***
D 60 - 81	46	
<b>Leg Dominance</b>		
Right	50	R/L 1.16, 0.53-1.79
Left	43	
<b>Previous Injury</b>		
Yes	30.6	Y/N 1.53, 0.91-2.35; ↑**
No	20	
<b>Skier Type (T)</b>		
TI	26.7	T3/T1 1.99, 1.05-2.87; ↑**
TII	37.5	T3/T2 1.42, 1.02-1.80; ↑*
TIII	53.1	T2/T1 1.25, 0.46-2.61

**Key: Skier Type (T)**

TI Cautious, gentle to moderate terrain, slow to moderate speed

TII Does not meet skiing style description of either I or III, adapts speed to conditions

TIII Aggressive, steep terrain, fast

**Comparisons**

Effects clear at the non-clinical 90% level and likelihood that the true magnitude when effect is positive ↑, negative ↓, \*small, \*\*moderate, \*\*\* large

Self-release Type I and II female skiers had ski-bindings with lower torques than males (Range, 20.9 – 61.4 Nm versus 50.6 - 87.9 Nm). Only one skier, a female, reported performing the self-release prior to each day of skiing, which was a routine adopted after leg injury and undertaken on release settings lower than ISO

recommendations. Self-adjustment followed by self-release did not always result in safe release settings (see Table 6.4).

Table 6.4: Modifying effects of characteristics success in self-adjustment.

	Clinical Inference	Confidence Limits	CLtd
<b>Skier Type</b>			
I + II	Likely benefit *	0.87 - 1.84	1.45
III	Likely harm	0.24 - 1.09	2.14
<b>Binding Age</b>			
0-1 years	Possibly harm	0.32 - 1.33	2.03
2-4 years	Unclear	0.36 - 1.55	2.07
5-18 years	Unclear	0.47 - 1.82	1.97
<b>Skier Days</b>			
0-7 days	Unclear	0.30 - 4.01	3.67
8-28 days	Possibly harm	0.48 - 1.39	1.70
> 28 days	Unclear	0.32 - 1.32	2.02
<b>Gender</b>			
Male	Unclear	0.66 - 1.38	1.45
Female	Possibly harm	0.13 - 1.68	3.66
* CI 99%, release setting within 15% tolerance of the reference point			

### 6.3 Discussion

With regard to the purpose of this study, the self-release test was not a valid alternative to machine torque testing for assuring safe ski binding release torques in recreational skiers of any ability. Other findings were: 1) skiers with more advanced skiing style were more likely to have release settings that were higher than the ISO recommended setting, ski-bindings set too high may not release under load and increase the risk of injury; 2) both female skiers and males could self-release, however, females required lower torques than males with the self-release torque at the toe-piece with limited parity to the ISO recommended torque; 3) there was no ski boot wear and tear measuring system; 4) no private or rental skis had ever been machine torque tested; and, 6) ski equipment that was greater than 30%

over tolerance under ISO standard 11088 required immediate maintenance and further torque testing.

Self-release test was not a valid alternate to machine torque testing for assuring safe ski binding release torques as only 28% of participants could release on ISO recommended release torques, all others required lower release settings. Were skiers to utilise lower settings inadvertent release may occur. Unexpected releases on moderate to steep inclines could potentially result in injury (88).

Skiers with more advanced skiing styles (Type II and Type III) were more likely to have S-B-B systems over the recommended release value than Type I skiers. Exposure to risk of non-release at high settings seemingly based on a skiers informed decision (83). Advanced skiers can choose to ski less aggressively at speed on less challenging terrain, when the visibility is limited or the snow conditions are not optimum. A change of skiing style would mean that the higher release settings for a Type III skier would not always be required. Ski-bindings set too high may not release under load and increase the risk of injury.

Females required self-release torques that had limited parity to the ISO recommended torques. We found female skiers that self-adjusted to achieve self-release were less likely (66%) to have normal or high torques when compared to male skiers (Range, 20.9 – 61.4 Nm versus 50.6 - 87.9 Nm). Female skiers were less likely to self-release as they utilised hamstring torques rather than quadriceps torques as used by male skiers (86). In this study, isokinetic torque measurements were not collected limiting commentary on muscular strength differences between genders.

The number of days skiing had no effect on self-release torques and ski fitness seemingly made no contribution to self-release capability. Leg dominance also did not predict successful release. The utility of the self-release test was further restricted in skiers with a history of previous leg injury during the second or third attempt. Over half of the previously leg injured group could not release on lighter settings. Were previously knee and/or lower leg injured skiers to rely solely on the self-release manoeuvre to determine safety of the ski binding, re-injury risk could increase.

There was no boot wear and tear grading system, which was concerning given that ski-boot soles need to be compatible with the binding. To the knowledge of these authors, there is no device available for checking the boot sidewall on the torque-testing machine, only a boot sole length measurement. The 28 pages of technical specifications in ISO 5355 Alpine ski boots – Requirements and Test Methods, had no categorisation of wear that could be quickly translated to the workshop floor hence the creation of a grading system. Tribology terms that described interactions between surfaces were taken into account to create the grading system. Possible descriptions when determining the grading descriptors for this study were fretting or fine wear of surfaces, scoring or advanced scuffing and spalling where flakes of a material are broken off a larger solid body leading to surface failure. Although Grade 3 boot wear and tear was uncommon (14%), regular checks of wear and tear or grit on the boot surface are needed to ensure retention in the binding in normal skiing manoeuvres (see Figure 6.3).



Figure 6.3: Grade 3 wear and tear

The lack of annual torque testing of private and rental skis was concerning. Given that skiers travel at speed, no warrant system to check ski-binding reliability meant that all of the participants had exposure to equipment malfunction. Internationally skiers are encouraged to have ski equipment torque-tested annually, with some insurers asking that an injured skier provide proof of recent testing and

correct set-up (124, 152). Torque-testing is not required in the New Zealand no-fault universal cover system (Accident Compensation Corporation - ACC); however, under the new Health and Safety in Work Act (2016) employers could require such tests to protect staff that work on skis (217).

All skis  $\pm 30\%$  from the reference point required maintenance to ensure the spring and lever was functioning correctly followed by adjustment. Ski-bindings retaining a Class III (more than  $\pm 45\%$ ) need discarding). Arguably,  $+15\%$  from the reference point potentially leads to release values that are too tight for at risk groups and these ski-binding-boot systems should also have maintenance. New ski bindings were more likely to have higher torques than older ski equipment. Relying solely on the release indicator would not provide the skier with sufficient information on the exact release torque. Skiers using bindings that were too tight may not release from the binding when falling. Torque transferred to bones and ligaments in non-release could result in injury. Under-tolerance also raises concern that skiers are not retained in the binding during normal skiing manoeuvres.

#### **6.4 Conclusion**

The alternative testing method of the self-release manoeuvre with self-adjustment did not accurately determine safe set-up for recreational skiers. The self-release test indicated that the spring and lever system could only open for some skiers. Regular torque testing of the binding spring and lever systems and correct set-up remains an essential component in injury prevention. Skiers that self-identified as Type III were more likely to self-release; however, regardless of the confidence gained with experience the self-release manoeuvre did not assure safety. A high proportion of ski equipment set-up was sub-optimal placing the skiers at risk. Additionally, there was no easy to use ski-boot wear and tear grading system highlighting a gap in the present standards. The three-level grading system descriptions on boot wear and tear that were developed could benefit ski technicians advising skiers, provide text for injury prevention messages, be of use in other research and included in international standards. The accuracy of skier style selection was not tested on-slope warranting further investigation of accuracy in reporting skiing style for ski-binding set-up. Potentially skiers' were placing themselves at undue risk with higher release settings calculated by overstating ability. The self-release manoeuvre is not

an intervention that can replace machine testing. The results of this study suggest torque testing with a machine needs to become a routine part of the safety landscape for skiers in New Zealand and beyond. All New Zealand ski areas and ski rental shops would benefit from torque-testing services. An education intervention on safe set-up of ski equipment is also required.

## **6.5 Limitations**

No isokinetic testing was undertaken. The effect of muscle strength on ability to self-release was not established.

## CHAPTER 7 – REAL WORLD OUTCOMES

### Prelude

Sustainability of the national snow sports injury prevention programme was under question at the outset of this thesis. Sports organisations receiving injury prevention programme funding were facing increased demands from the New Zealand Accident Compensation Commission (ACC) for planning and evaluation. Ski Areas Association New Zealand (SAANZ) executive were cognizant of the constraints of the government annual funding model. Regardless of external funding, members of SAANZ (all commercial ski areas) had collaborated on injury prevention since the inception of the association 35 years ago. Clearly, continued collaboration on injury prevention initiatives between ski areas and external parties was desirable. Creation of an evidence-based injury prevention strategy, led by industry, was determined to be the best way forward. After working through the TRIPP framework in the original studies in the thesis, in this chapter the question is not do we know everything, but rather, do we know enough to develop an injury prevention strategy. This chapter draws on scientific evidence, practice-based information and the operational context of snow sports to complete TRIPP stage 5. Development of annual action plans within the strategy for 2015 to 2020 execute TRIPP stage 6 – implementation of evidence-based interventions.

## 7.1 Introduction

The New Zealand Accident Compensation Commission (ACC) established the SportSmart injury prevention programme to support targeted interventions for sports that represented 40% of the injury claim costs (45). Despite government investment in alpine skiing and snowboarding injury prevention over 18 years in the period prior to SportSmart and during this injury prevention programme, there was limited evaluation. For example, ACC purchased 8,500 wrist-guards (2000-2001) for distribution to ski areas and rental facilities; wrist-guard usage and the incidence of snowboarding wrist injuries were only reported in a SAANZ technical report (14). Numbers of injured snowboarders wearing versus not wearing a wrist-guard were low (8 vs. 32 in 2000 and 14 vs. 55 in 2001). There was no data on the proportion of snowboarders uninjured wearing ACC funded wrist-guards, limiting conclusions. ACC provided no wrist-guard funding to ski areas after 2001. The lack of evaluation data potentially thwarted the argument for continued ACC funding for the wrist protection initiative. Evaluation plans need to be set-up prior to an intervention (46). Successful programme monitoring requires four modalities that review the concept, process, impact and the outcome.

Evaluation data on the ACC SportSmart injury prevention programme focused on team sports, mainly Rugby (45, 218). The scrum rule-change interventions that led to a decline in cervical spine injuries were food-for-thought; what rule changes could reduce injury risk in recreational snow sports in this country? SAANZ last reviewed and endorsed the New Zealand Snow Users Responsibility Code in 2004, a safety code loosely based on Canadian ski area rules (see, Appendix IX). A national education campaign bolstered by motorcar funding disseminated the safety information on lift towers and on posters at ski areas for several years (14). SAANZ had not reviewed the eight-rules; begging the question, were these rules still pertinent?

Federation Internationale de Ski (FIS) established a skier's code of conduct (219, 220) constructed of 10 rules in 1964 (see, Appendix IX). Were the FIS rules contemporary? To not endanger others, FIS rule number five indicated that the skier must look up and down before entering the slope and not stop unless absolutely necessary. Only 34% surveyed (n=1450) in Austria's Tyrolian ski areas knew that FIS had determined slope rules (219). Concerning was learners, young skiers and

non-Austrian residents were not familiar with the FIS moving rules; three groups that are more likely to stop in the middle of a slope due to lack of skill and/or lack of terrain familiarity. FIS rule two had four key concepts; control, adaption, speed related to ability, and speed related to conditions. Multiple concepts in one rule could lead to information overload where skiers and snowboarders are not able to remember the safety rules (38). The portability of public safety information for the great outdoors that had been developed in New Zealand after 2004 needed to be considered.(221). Where a skier or snowboarder breaks a ski area rule, injury to others is a risk. Cancellation of lift passes is a potential consequence of rule breaking in New Zealand and abroad. Fit-for-purpose snow safety rules that reach all users are a more positive construct than policing. However, changing risk-taking behaviours clearly requires more than rules (36).

The Swiss Council for Accident Prevention (bfu) tackled the complexity of injury prevention in alpine skiing and snowboarding by developing an effect-orientated injury prevention cycle and a national snow sports injury prevention strategy (46). Five steps completed by the bfu before moving to a new cycle were accident research, prevention goals, prevention programmes, implementation of measures and monitoring success. Notably, a lack of implementation and prevention measure data was the catalyst for qualitative panel discussions and rating risk factors. The top six Swiss risk factors relevant in snow sports accidents were: trail area design not optimal; insufficient awareness of danger and lack of self-regulation; excessive speed; lack of physical fitness and balance; inadequate skill and lastly, ski binding set incorrectly or inefficiently. From a practice-based pragmatic viewpoint tools used to reduce risk in other injury prevention programmes are probably portable (222, 223). However, not all injury prevention strategies used abroad might translate to New Zealand. Unique local challenges include ski areas on an active volcano, ACC no-fault legal statutes, and “Kiwi” (local idiom for a New Zealand citizen) social mores. The behaviours and attitudes observed in skiers and snowboarders in other jurisdictions probably are similar; however, this hypothesis was not tested.

Debate on evidence-informed sports safety policy and associated research that emanated out of Australia, Norway, and Canada highlighted that sports injury prevention programmes require long-term investment not short term funding (31,

224, 225). Canada estimated that evidence translated to policy could lead to a reduction of 20% of youth sport injuries. Switzerland (bfu) identified the need to reduce the burden of snow sport injuries with two-prong strategies that reduced incidence and severity (46). Partnerships between research centres, community and government were integral to the success of interventions for reducing the burden of injury.

Without agreed strategy and action plans, one off interventions will most likely not prevail. Random activity in injury prevention notably could lead to disenfranchised stakeholders, poor participant uptake and wasted resources (224). To counter similar negative events a ground-up consultative approach was promoted during strategy development (226). Stage 5 of the TRIPP framework required that before interventions commence description of the context was required (15). The purpose of this chapter is to develop an evidenced-based injury prevention strategy for snow sports specific to New Zealand that provides context description and evidence-based direction for SAANZ for the medium term.

## **7.2 Methods**

SAANZ executive provided written support for strategy development within the PhD in 2014. Ethics approval received from the Auckland University of Technology Ethics Committee - AUTEK 14/146. A stakeholder focus group, two surveys (August 2014 – December 2015), findings from previous chapters of the thesis and further review of the literature formed the basis for the development of the strategic document.

A stakeholder focus group established in 2015 provided expert input to strategy development recorded in meeting minutes, email communiques, and track-change commentary/questions. Representatives were from SAANZ, Snow Sports New Zealand, New Zealand Snowsports Instructors Alliance, New Zealand Snow industries Federation, New Zealand Mountain Safety Council, ACC, and Worksafe New Zealand. The focus group met in February 2015. All representatives of key organisations agreed to contribute to the development of an injury prevention strategy for Snow Sports. Online and in-person researcher engagement with the focus group occurred every two months in a cycle of plan, do, check and then act (PDCA) (227). Responses generated six PDCA cycles over eleven months and

feedback on six drafts of the strategy. No thematic analyses were made of the focus group responses. Both the focus and industry surveys group provided essential links with those on the ground.

Survey recruitment involved 36 invitations (with passwords) sent to heads of safety services and senior ski area staff identified by SAANZ at all commercial ski areas (2014, 2015). Two online surveys were undertaken using Survey Monkey (see Appendix X). Survey I provided data for strategy focus areas. Survey II garnered feedback on proposed new text in the snow safety code (action plan initiative for 2015). Analyses were made for recurring themes of the free text in open-ended questions in both surveys.

Systematic searches of PubMed, Medline, Cochrane, Google Scholar, and SportDiscus databases were performed for studies related to alpine skiing and snowboarding injuries published in English from 1990 using key words: skiing, snowboarding, injury, prevention, strategy, risk, safety, skill-development, skill-retention, snow, and the Boolean operators AND/OR. Contributions regardless of year were considered for inclusion from the anthologies of the symposium ‘Skiing Trauma & Safety I – XX’ by the International Society of Skiing Safety; seminal works related to injury prevention, risk management; grey literature, government documents (translated to English using Goggle Translate where required), and snow sports international equipment standards, were also reviewed. Inclusion criteria: patient population (alpine skiers and snowboarders), intervention (snow sports injury risk reduction), comparison (alpine skiing, snowboarding), outcome (people, equipment and environmental snow sports injury prevention programs), and settings (ski areas). PICOS protocol included all study design and small sample sizes. Meta-analysis was not undertaken. Exclusion criteria: all articles pre-carving ski era (<1993) were checked for application in the new equipment environment, cross-country skiing data with no transferability to the recreational downhill environment. Strategic development data from health, engineering and management with no clear portability to the mountain context were also not included.

### 7.3 Results and discussion

Response rate (n = 36) Survey I 61% and Survey II 66%. Importantly, all of the SAANZ heads of safety service working group responded. These respondents were ski area personnel invested in injury prevention and able to influence decisions at ski areas. The first survey provided information for developing the strategy. Survey I also provided a mandate for replacing the snow users' responsibility code, data that informed development of the strategy 2015 action plan. The safety concerns, ranked by percentage of response observed in Table 7.1 found the highest concern was a perceived mismatch between the actual ability of skiers and snowboarders and appropriate selection of terrain.

Table 7.1: Survey I ranked order of safety concerns

 <p>Highest</p> <p>Lowest</p>	55%	I. Ability vs terrain mismatch.
	36%	II. Lack of environmental knowledge.
	32%	III. Low safety service staffing numbers and experience affecting mitigation and incident management.
	23%	IV. Collisions (other users, sliders, manmade hazards and rocks).
	23%	V. Lack of protective equipment (head and wrist).
	23%	VI. Serious nature of injuries.
	18%	VII. Back country access and lack of preparedness (no partner, limited use of avalanche beacons).
	14%	VIII. Speed not adjusted to conditions (congestion, visibility, ice and other snow conditions).
	9%	IX. Lack of respect for others on the slope, particularly learners.
	9%	X. Rule-breaking (ignoring closures and other signage).
	5%	XI. Run away snowboards.

Lack of environmental knowledge ranked next in level of concern. No data were gathered on terrain maps and information provided on ski runs. The proportions that were concerned are a red flag that this information is insufficient and/or inappropriately conveyed. Ski patrol staffing numbers at some ski fields were seemingly stretched as evidenced by 32% of respondents raising concern that numbers on the ground to help implement injury prevention initiatives were insufficient. It is beyond the brief of this thesis, to influence ski patroller staffing numbers. Injury prevention is not solely the responsibility of ski patrol/safety services. Everyone has a part to play in the dynamic mountain environment.

Inadequate protection, collisions and injuries of a serious nature were deemed equally important (23%). Speed, lack of respect and ignoring closures were of lowest concern. Speed is part of the thrill of alpine skiing and snowboarding and also a risk factor, the challenge is how best to enhance the fun of moving fast and reducing the risk (228).

Given Survey I involved a small number of participants more research is required on these risk-taking behaviours. Snowboards lack brakes and may not stop when a boarder drops a snowboard walking between trails raising concern with 5% of the participants. One experienced snowboarder died in New Zealand in 2013 after a catastrophic fall retrieving a runaway snowboard, although rare, clearly this tragedy remains in the minds of ski staff involved in this tragedy.

As part of Survey I, respondents identified injury-prevention focus areas (see Table 7.2). The key foci were around education, environment and equipment. This data informed strategy development and action-plan design. The main findings identified a need for education on environmental hazards, national standardised signage, and improved terrain maps. Wider trails and improved egress at chairlifts proffered as environmental solutions, and increased usage of protective equipment. Also identified was the need to increase equipment checks.

Table 7.2: Injury prevention focus areas

- Education (skiing and snowboarding lessons, safety rules, etiquette, environmental hazards).
- Environment (wider trails for learner and high use areas, improved egress from chairlifts).
- Signage (update and agreed national trail merge signs, clearer descriptions of grade/terrain).
- Better maps that explain terrain and improve choices.
- Speed control in congested runs and lift loading areas.
- Equipment checks (ensure ski-bindings are operational and enforce snowboarders to use leg ropes).
- Protective equipment (increase usage of helmets and wrist-guards).
- Re-design ski bindings (particularly for beginners).

A presentation to SAANZ conference delegates in Wanaka, New Zealand in October 2015 included an overview of strategy development, Survey I results, and a draft version of the new snow safety code. The presentation generated divergent opinions and healthy debate from conference delegates (SAANZ members). A vote taken at the conference on changing the code name from Snow Users Responsibility Code to the Snow Safety Code found all SAANZ members in favour. A second vote on circulating a second survey to all SAANZ members on a wider range of safety code text also found all in favour. Feedback provided from Survey II in the free-text highlighted the complexity of the task of safety code development (see Table 7.3).

Table 7.3: Open-ended feedback on draft code

*"It is good to see progress has been made in redeveloping the snow safety code".*

*"Once you get into debating the content of the code you realise how difficult it is".*

*"The selection of rules in the draft code is possibly still the most relevant set but the language needs to change".*

*"The draft code is almost exactly like the old code".*

*"The language needs to be contemporary, clear, consistent and more memorable".*

*"How the code will be presented needs to be considered. Bite size messaging will be more effective than presenting all points together".*

*"A sentence under a broad heading is possibly the best way to deliver the messages".*

*"The challenge is not only strong messages but ones that can easily be converted to a graphic".*

*"We need to keep our focus on the snow safety code as a tool for "injury prevention" not a set of ski field rules, particularly if our aim is to keep it simple".*

*"Delete stay on scene, rubbish, respect gets respect" (n=2)*

*"We need to focus on the high frequency risks rather than lower frequency risks, like ducking rope lines".*

Safety messages to be included in the new code were “stay in control at all times”, “respecting others on the slope”, “obeying the signs”, and “ride to the conditions and your ability” (see Table 7.4). Text of least importance to respondents was “control your speed”; a response possibly due to the fact no geographical area was specified or that the fun of speed implicit to snow sports would be quashed. Phrases that warranted a rewrite possibly alluded to respondent beliefs that these were not general safety messages for all ski area users. The top four phrases in this category were: “use recently serviced equipment”, “know your limits”, “don’t lose what you use”, “equipment or rubbish”, “protect your head (and wrist if less than 30 days riding”, “snow sports are physically demanding, drink and eat regularly” and “reduce exhaustion, drink and eat often”. Helmet wear was an action supported by SAANZ in online material, required by SAANZ at some ski areas for staff working on snow (e.g. ski patrollers, snow sports instructors and operational staff on ski lifts). However, only the artificial snow dome mandated helmet wear for recreational users. Rubbish on slopes can create hazards; this environmental risk is suited to operational staff solutions such as appropriate placement of rubbish receptacles and initiatives such as less pre-packed foodstuffs and plastic bottles sold at ski areas. Regular intake of food and fluid to prevent exhaustion messages were ACC SportSmart recommendations. Prevention messages related to the risk of poor performance and poor decision-making secondary to inadequate intake possibly are better suited to targeted education campaigns. Overall, both surveys provided evidence for the 2015 strategy action plan, support for replacing the existing Snow Users Responsibility Code, and direction for the final text in the brand-new New Zealand Snow Safety Code.

Table 7.4: Proposed new safety code text

	YES	MAYBE REWRITE	NO	NO RESPONSE
Stay in control at all times	53%	10%	37%	-
Respect gets respect	58%	21%	16%	5%
Stay injury-free	21%	26%	37%	16%
Obey ski area signage, it's for your safety	42%	37%	5%	16%
Obey the signs	47%	37%	5%	11%
Ride to the conditions and your ability	47%	16%	16%	21%
Chose terrain that matches ability	26%	37%	11%	26%
Know your limits, choose terrain that matches your ability	21%	32%	32%	15%
Know your limits	32%	47%	11%	10%
Control your speed	63%	16%	11%	10%
Control your speed in congested areas	16%	37%	16%	31%
Don't lose what you use, equipment or rubbish	16%	47%	16%	21%
Don't lose what you use	42%	42%	5%	11%
Share the slopes and give others space	42%	21%	11%	26%
Share the slopes, give way to others	26%	42%	16%	16%
Give way to riders below	32%	26%	26%	16%
Give way to people below	37%	32%	16%	15%
Wear protective equipment	21%	42%	21%	16%
Protect your head (and wrist if less than 30 days riding)	5%	47%	16%	32%
Protect your head, wear a helmet	37%	37%	16%	10%
Protect your wrist, wear a wrist-guard	5%	42%	32%	21%
Use correctly set-up equipment	21%	42%	16%	21%
Use recently serviced equipment	21%	58%	11%	10%
Snow sports are physically demanding, drink and eat regularly	16%	47%	21%	16%
Reduce exhaustion, drink and eat often	21%	47%	16%	16%

The systematic review of literature examined 944 abstracts or full articles, of these 641 did not meet the inclusion criteria. Of the literature reviewed, 314 articles or standards and grey literature informed development of a national injury prevention strategy. No single how-to template for developing sports injury prevention strategies existed (229). There were a plethora of business, operations, and health management authors promoted formulae, action cycles, and purpose and value statements. Within the data, the continuum from conceptualisation to completion clearly was not linear. Quality improvement methodologies looked at people, organisation and technical systems. Although design principles applied, the product in this instance was a one-off strategy for use in a specific time period (230). An identified weakness designing a strategy was insufficient or out-dated evidence (222). Using a top-down approach was another negative; conversely, a strategy that was logical to the end user and designed in collaboration with industry was viewed as a strength. Both the focus group and surveys provided essential sector engagement and helped frame the strategy. A treatise of the literature and pertinent findings from other sections of the thesis included in the developed strategy spans TRIPP stage 5 – the operational context and TRIPP stage 6 – implementation and evaluation. The developed strategy, the final result of the thesis presented below.

#### **7.4 The developed injury prevention strategy**

##### **New Zealand Snowsports Injury Prevention Strategy (2015- 2020) – a snow sports industry initiative**

###### **7.4.1 Strategy executive summary**

This strategy is a blueprint to reduce injury incidence in snow sports and enhance joint-venture injury prevention efforts across New Zealand ski areas from 2015 to 2020. Ski Areas Association New Zealand (SAANZ) is the lead organisation in this initiative with key industry collaborators: Snow Sports New Zealand, New Zealand Snowsports Instructors' Alliance, and New Zealand Snow Industries Federation. Based on analysis of the problem, specific goals have been established, a set of actions planned, and a flexible time-line determined for interventions. The Accident Compensation Commission (ACC) will be the key government joint-venture partner on initiatives that planned for the next five years and other potential external collaborators identified.

## General overview of the problem

For every 1000 people who enjoyed the slopes in the five winter seasons 2010 to 2014, approximately nine people sustained injuries skiing or snowboarding; one third of these people were assessed and treated at mountain clinics, while the remaining two thirds (mostly minor injuries) by-passed mountain clinics seeking assessment and treatment off-the-hill. Claims paid by the ACC for skiing and snowboarding injuries in 2014 were \$20.3 million. Cost in terms of quality of life may be much greater as an individual's well-being has the potential to be affected by injury over months or years. Future participation in snow sports by the injured skier or snowboarder and their family or friends may also be compromised. A decline in snow sports participation impacts negatively on ski-area, resort and ski-industry economics. In short, injury is bad for business.

## Goals

- Reduce the injury rate by 10% over the next 5 years.
- Increase enjoyable injury-free recreation at New Zealand ski areas.
- Collaborate to increase effectiveness and ensure the sustainability of this strategy.
- Inform decision-making with best-practice evidence and evaluation.
- Develop and implement appropriate injury prevention interventions.

## Planned actions

- Target reduction of specific injury types (for detail, refer to the risk factors and the annual plans).
- Rewrite the Snow User Responsibility Code in a more memorable format.
- Educate skiers and snowboarders on proper safety and control on the slopes.
- Promote skill development.
- Increase physical conditioning messages that are specific to snow sports.
- Increase the use of international equipment testing and set-up standards.
- Promote protective equipment that meets international standards.
- Continue to provide regular snow condition and visibility updates.
- Enhance injury-hotspot surveillance to better inform trail and terrain-park design.

#### 7.4.2 Strategy introduction

New Zealand (NZ) is an active outdoors orientated nation with more than 1.3 million ski or snowboard visitations over a winter season. The indoor snow dome in Auckland extends the opportunity for many more people to enjoy being active on snow all year round. Injury prevention has been an integral part of NZ ski patrol and mountain operations for over sixty years, and as such this injury prevention strategy benefits from expertise built over many years, in tandem with current best safety service practices (231, 232). Injury is not outside of human control and is therefore not an acceptable part of snow sports; injury is predictable, preventable, and treatable (5, 6). Opportunity exists in NZ to reduce both the risk and the severity of injury in snow sports. The injury prevention strategy 2015 to 2020 implementation plans will provide direction for injury prevention efforts across all NZ commercial ski areas, club ski areas and the indoor snow dome (all are members of SAANZ). Joint-venture activity with affiliated organisations will also be enhanced. This strategy is an essential part of the mission to take 'all practicable steps' to provide a safe play and work place.

#### Overview of the problem

For every 1000 people who enjoyed the slopes in the five winter seasons 2010 to 2014, approximately nine people sustained injuries skiing or snowboarding; one third of these people were assessed and treated at mountain clinics, while the remaining two thirds (mostly minor injuries) by-passed mountain clinics seeking assessment and treatment off-the-hill. Claims paid by the ACC for skiing and snowboarding injuries in 2014 were \$20.3 million. Cost in terms of quality of life may be much greater, as an individual's wellbeing has the potential to be affected by injury over months or years. There is a paucity of quality of life research specific to snow sports, but there is other quality of life research with transferable pertinent findings. For example, difficulty with self-identity, depression and deterioration of quality of life was found in traumatic brain injured New Zealanders (18). Future participation in snow sports by the injured skier or snowboarder and their family or friends may also be compromised. A decline in snow sports participation impacts negatively on ski-area, resort and ski-industry economics (233, 234). In short, injury is bad for business. The actual financial impact of injuries on SAANZ members, NZ

Snow Industry Federation (NZSIF) members, and mountain communities is yet to be determined.

### **7.4.3 General framework**

The NZ Snow Sports Injury Prevention Strategy is a blueprint to accomplish injury prevention. SAANZ is the lead organisation in this strategy. All ski areas in NZ are members of SAANZ. The Heads of Safety Services group (HODs) is a subcommittee of SAANZ. All other snow sports organisations represented in the injury prevention steering committee are organisations affiliated with SAANZ; namely Snow Sports New Zealand, NZ Snowsports Instructors Alliance and the New Zealand Ski Industries Federation.

Based on analysis of the problem, specific goals have been established, a set of actions planned, and a flexible time-line determined. The economics associated with collaboration and scale will benefit ski areas, ACC, and other organisations that partner with SAANZ on injury prevention projects. Ultimately collaborative endeavour will benefit the community who recreate on the snow.

SAANZ is one of a small number of sports organisations that collects participant numbers, maintains injury surveillance using a national registry for incidents treated at all commercial ski areas, and has actively supported injury prevention research; these are key elements for an injury prevention programme. The injury surveillance system utilised by ski area safety services and mountain clinics moved from a paper-based incident reporting to the National Incident Database to Snowsports (NID-S) New Zealand Mountain Safety Council (MSC) on-line platform in 2005. The investment by SAANZ on updates to the database infrastructure and data entry over the last decade places the association in a good position to evaluate injury data, injury trends and the efficacy of injury prevention interventions. This investment included support to redevelop the SAANZ incident reporting form (see Appendix II) into a more expansive data collection tool (235) prior to commencement of the data collection for a five year injury trend study (2010 – 2014). The patient-reporting section of the SAANZ incident form was also improved to meet accident and medical clinic accreditation requirements.

Other databases can contribute to description of injuries in snow sports in NZ, namely the ACC claimant database and the regional district health boards (DHB) databases. All three databases have some limitations. Different injury definitions and coding systems create challenges when comparing data (23, 103, 236). The NID-S uses simplified diagnostic code for up to three injuries for one individual. ACC uses a single Read code from a list of 33,880 codes for an individual claimant; multiple injuries are not captured in this code. Discordance relating to diagnosis may also occur when assigning Read-code (136, 137). The DHB use International Classification of Diseases, ICD-10 code. DHB in-depth information on severity would be useful; however, researchers trying to extract information on snow sports and lift injuries in Otago found the task difficult (54, 55). DHB data could be useful in future snow sports injury health outcome research at a district level but would not be of use in determining the success of this national injury prevention strategy. The NID-S and ACC databases are comprehensive registries. Both ACC and the NID-S were checked for accuracy and utility using 2010 – 2011 data sets. Missing data was found for less than 2% of cases, these blanks did not affect determination of a diagnosis. ACC costs provide a more consistent measure for determining the severity of the injury than the NID-S severity status coding. Reports from the NID-S can be generated by ski patrollers and mountain clinic staff as required, providing a close to real-time picture. There is no regular in-season information on injury trends provided by ACC to SAANZ. In combination both databases will provide comprehensive information to evaluate the effectiveness of injury prevention interventions.

The World Health Organisation Ottawa Charter (1986) call to enable people to mediate and advocate for good health underpins this strategy (2, 31, 237). The development of this strategy benefited from the advocacy of individuals that are passionate for sustained positive change. Short-term actions could lead to wasted resource, disenfranchised investors, and no capability to measure the impact and determine whether the intervention/project was successful. Consensus and cooperative action occurred during the development of the strategy to mitigate such risks. Alongside the ground-up development steps, a comprehensive literature review was completed and analysis of injury trends over five winter seasons. Various authors have developed epidemiological, biomechanical, and cost-benefit injury prevention models to provide structure to both the search for answers and the

implementation of solutions (15, 17, 21, 22, 32, 33, 45, 46, 222, 238, 239); this comprehensive range of sport injury prevention models were reviewed to determine an appropriate way forward for SAANZ. The effect-orientated prevention cycle (see Figure 7.1), Translating Research into Injury Prevention Practice (TRIPP framework, see Figure 7.2), and cost-effectiveness were selected as models/tools to be used by SAANZ to achieve the following specific goals: reduce the injury rate by 10% over the next 5 years; increase enjoyable injury-free recreation at New Zealand ski areas; collaborate to increase effectiveness and ensure the sustainability of this strategy; inform decision-making with best-practice evidence and evaluation; develop and implement appropriate injury prevention interventions.

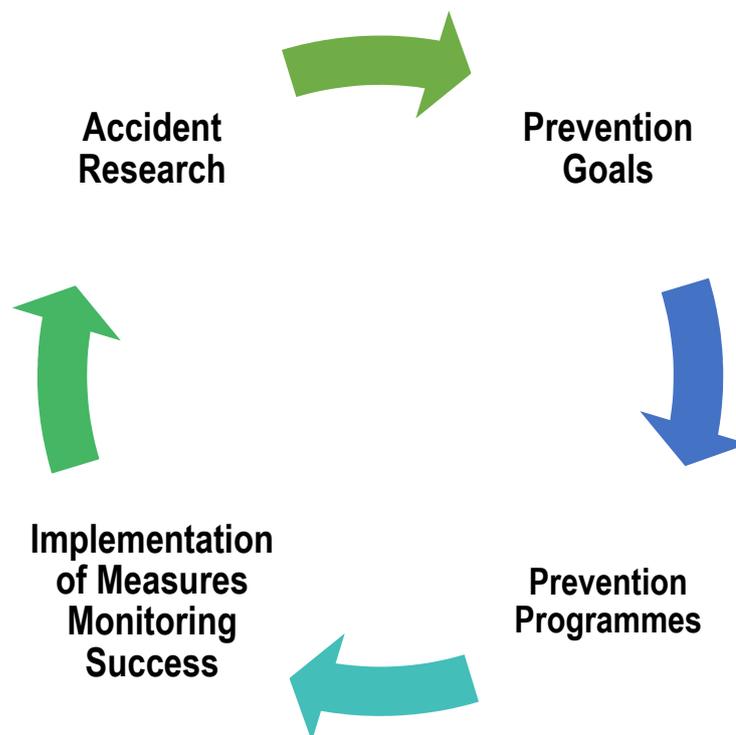


Figure 7.1: Effect-orientated prevention cycle developed by the Swiss Council for Injury Prevention (adapted from Bianchi and Brügger, 2015).

Unlike other injury prevention models utilised in sports injury prevention the effect-orientated prevention cycle (46) quantifies clear goals that should be achieved. Importantly for SAANZ this cycle/injury prevention model has effectively been applied in snow sports. Key to the success of the effect-orientated cycle is that objectives and priorities are defined by researchers; education resources are developed; there is provision of a wide range of courses to the snow sports sector; advice and support is provided to people who can multiply the reach of the injury prevention programme; and, robust communication occurs prior to the

commencement of safety campaigns. All measures are co-ordinated and implemented in cooperation with snow sports industry and community partners. Continually fostering relationships is key to the success of the effect-orientated injury prevention cycle. Sport is viewed as unique in terms of injury prevention strategies, the top-down approach of legal regulations used to reduce road trauma was viewed as not being transferable to sport (46, 240). Rather than regulate, the bfu has an inclusive ground-up approach to injury prevention, an approach that resonates with the established practices of SAANZ. The effect-orientated cycle incorporates research; the TRIPP framework provides SAANZ with more detail on the stages required to research effectively. Importantly the TRIPP framework considers the industry context and there is a practical emphasis on translating injury prevention research into interventions for the real world (3, 15, 241, 242). An example of application of the framework can be found in the strategy section entitled “addressing the risk triangle”.

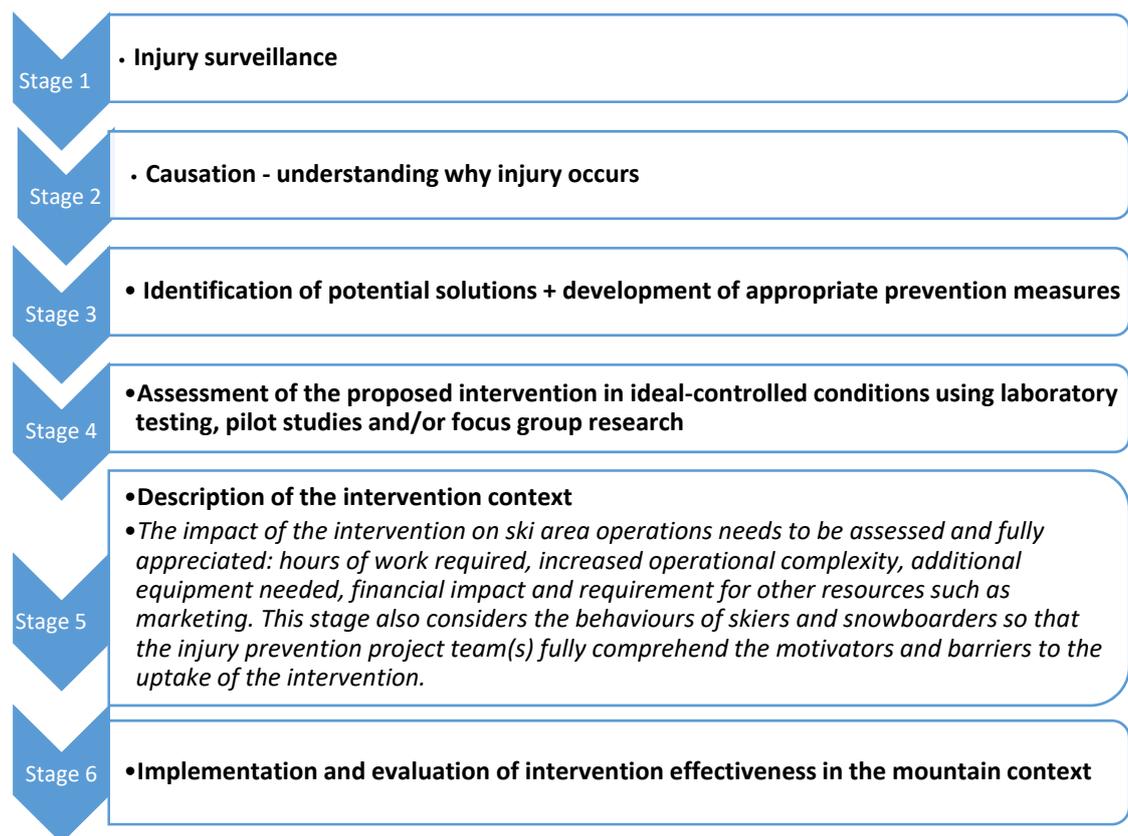


Figure 7.2: The six stages of the TRIPP framework (adapted from Finch, 2005).

### Cost effectiveness

When Heads of Safety Service departments apply for ski area investment there is an accounting bottom-line, a requirement to quantify the need for the intervention plus present a reasonable level of proof that demonstrates likely success. Limited company resources potentially challenge resourcing injury prevention initiatives, the benefits of injury prevention initiatives may not be immediate, and/or there may be competing demands of other departments. Understanding the modifiable risks and providing detail on how much the intervention will cost is key to developing viable interventions (81, 243, 244).

ACC also use formulae to determine decisions on the level of investment in injury prevention. When seeking funding from ACC to partner in injury prevention initiatives SAANZ will need to be cognizant of the present funding formula and the expectations that ACC has for return on investment (45). Other government departments or crown entities will have similar burdens of proof to those required by ACC before making investments in snow sports injury prevention initiatives.

Commercial sponsors will calculate the fit of their product or service being associated with injury-prevention projects. Companies will also want to calculate the likely product exposure in the short or medium term, and the cost-effectiveness of being involved with projects that have a benefit to society.

### Health and safety legal framework

The legal framework for health and safety sets out how SAANZ, affiliated organisations, and individuals should operate to ensure benefit rather than harm. Many ski area staff, ski or snowboard during work and when recreating. The injury prevention measures in this strategy apply to both the public and ski area staff. The Health and Safety in Employment Act (1992) and the Machinery Act (1950) will be replaced by the Health and Safety in Work Act on the 4 April, 2016 (217, 245). Worksafe New Zealand provides health and safety tools and resources. Injury prevention interventions that reduce serious harm injuries have priority. Reports on serious injury outcome indicators are published by Statistics New Zealand annually (246). SAANZ and other investors in this strategy will continue to take 'all practicable steps' to provide a safe play and work place that integrates current legal mandates with the evolving safety culture of snow sports.

#### **7.4.4 Ensuring strategy success**

To ensure the success of the New Zealand Snow Sports Injury Prevention Strategy (2015 - 2020), knowledge gaps will be closed, investors empowered and system evaluation capacities will be increased. To ensure cooperation on injury prevention initiatives continue to thrive, good practice preventing injuries will have a higher profile than presently exists. Reward and recognition systems for injury prevention champions will be put in place by SAANZ and other strategy investors (46). The progress of each intervention or injury prevention project will be evaluated annually. Overall evaluation of the effectiveness of the 2015 – 2020 strategy will take place in 2020, and new actions will be determined.

**The following stakeholders are required to be investors in the success of this strategy:**

**Ski Areas:** those who work in safety and medical services; skier and snowboarder education; coaching and competition; and mountain operations staff are invested in injury prevention each day. The phrase ‘all practicable steps’ is important in the general duties of all people that work at ski areas as this phrase describes the standard of reasonable endeavour that each person must meet when carrying out their duties under health and safety law. The safety service heads of department (HODs) will have delegated responsibility and provide the co-ordination required to implement the strategy. This strategy is designed to enhance the capacity of those working on the ground to prevent injury.

**NZ Snowsports Instructors Alliance (NZSIA):** as a member of ISIA (International Snowsports Instructors Association) NZSIA provides international level training and qualification for instructors; incorporating Ski, Snowboard (SBINZ) Telemark and Adaptive divisions. This strategy is designed to ensure that those people developing the instructors’ curriculum and teaching the Snow Sports NZ FUNdamentals programme are afforded contemporary injury prevention information that will enhance instructors’ capacity to teach safe behaviours, assess physical alignment, provide physical conditioning advice, and teach skiing and snowboard riding techniques that have the potential to mitigate or reduce the severity of injury.

**Snow Sports NZ (SSNZ):** provides the FUNdamentals’ programme to teach and track children in the fundamentals of skiing, snowboarding, cross country skiing and

adaptive snow sports. The programme provides resorts in NZ with a consistent framework nationwide for delivering and tracking progression from basic to advanced skills in snow sports. This strategy is designed to expand education to all age groups around safety on the slopes, physical conditioning, skill acquisition and skill retention.

**NZ Snow Industries Federation (NZSIF):** those involved in the import of snow sports equipment, sale or rental of skis and snowboards, sales of protective equipment and accessories, are integral in the supply and service of safe equipment. Equipment needs to meet international testing, set-up and maintenance standards for product safety. This strategy is designed to ensure that those servicing both first-time and regular snow sports participants utilise the latest best practice standards, are resourced with current equipment-related injury prevention information, and in-turn that this information is conveyed to customers in a proactive way.

**People:** skiers, snowboarders and other alpine enthusiasts invest in participation time. This strategy is designed to ensure that the people that recreate in the mountains of Aotearoa, New Zealand are actively involved in injury prevention and are not impeded by the physical, psychological and economic stresses of recovering from injury.

**Community:** ski areas are an integral part of a local community that stretches out from day-trippers to those who spend a significant part of their lives in the mountains. Some skiers and snowboarders are employed at ski areas, whilst other individuals are involved in mountain club commitments, events in the mountains or on the indoor slope, and voluntary activity fund-raising for opportunities to compete. The wider mountain community are helping to future-proof the viability of the industry. The business success of resort towns and snow sports retailers throughout the country is intrinsically linked to clients having a safe injury-free experience and returning to the slopes on a regular basis. Airlines and rental car operators and the businesses enroute to the mountains are also investors. This strategy is designed to ensure that the wider mountain community continues to flourish, in part by playing an active role in injury prevention.

**Accident Compensation Corporation:** ACC is a key injury prevention partner. The ACC has provided a 24-hour no-fault personal injury scheme since 1974 and currently legislated by the Accident Compensation Act, 2001 (247). ACC provides universal no-fault coverage for most injury costs including medical treatment, compensation for loss of earnings, social rehabilitation and vocational rehabilitation. The Accident Compensation Act (2001) also provides for investment in injury prevention initiatives that deliver a positive return for levy payers. Investment in injury prevention initiatives are based on claim cost and volume, trends, and ability to influence the injury causes (248). This strategy is designed to ensure that ACC partnership with SAANZ is strengthened in terms of decision-making and co-ordinated action for initiatives that are jointly funded. Action includes development, implementation and evaluation.

**Other government affiliations:** Worksafe NZ is a crown agency established in 2013 with an independent board appointed by the Minister for Workplace Relations and Safety that carry out the health and safety functions described in the Worksafe New Zealand Act, 2013 (249). This strategy complements workplace safety plans specific to staff that are skiing or snowboarding during work and is designed to enhance collaboration between Worksafe NZ, ACC, and SAANZ. The Department of Conservation (DOC) has interests and responsibilities for public safety. A high proportion of NZ snow sport activities occur on the DOC estate. This strategy is designed for use in dialogue with DOC and the NZ Police who have overall statutory responsibility for all search and rescue (SAR) operations outside ski area boundaries. The NZ Police also has responsibility for road safety. Injury prevention on the roads is part of being able to enjoy snow sports. Safe access and egress from the mountains is not covered in detail in this strategy but the overlap of road safety messages with mountain weather reports is acknowledged.

**NZ Mountain Safety Council:** MSC encourages safe participation in land-based outdoor activities. The MSC maintains the National Incident Database-Snowsports (NID-S) for SAANZ. This strategy is designed to ensure that injury surveillance and evaluation of injury prevention interventions using the NID-S are fit-for purpose and adequately resourced; and that more joint-opportunities to disseminate snow sports injury prevention education and messages are created.

**Sponsors:** Snow sports attract branding opportunities for a plethora of products. Ski and snowboard equipment is often tested in the southern hemisphere in preparation for the northern winter, along with snow sports teams from other countries preparing their athletes for competition. Documentary and fictional filmmakers also engage in filming at ski areas or near the boundaries. Contribution or sponsorship from these parties to safety and national injury prevention should be considered in access agreements; this strategy is designed with a wider audience in mind.

#### **7.4.5 Investing in injury prevention**

This strategy details the injury problem facing the snow sports industry (SAANZ, NZSIF, SSNZ and NZSIA) and interventions to be undertaken by the industry to reduce the number of injuries by 10% over the next 5 years. The planned interventions will require investment by the industry and investors. The strategy is designed to steer the industry to meet its injury prevention goals and form the basis for the industry to attract partners who will also benefit from reducing injury in alpine skiing and snowboarding.

ACC Injury Prevention is an obvious partner, and the industry (through the former NZ Snow Sports Council) has successfully worked in partnership with ACC since 1999. The last substantive national investment by ACC in snow sports injury prevention occurred between 1999 and 2011 when ACC invested in interventions such as dissemination of the snow code; concussion resources; wrist guard research; supplying wrist-guards to rental outlets at ski areas and outlets in cities, towns and resorts; ski-binding standards research; National Incidence Database-Snowsports (NID-S) upgrades; terrain park signage; and point of sale injury prevention material distributed through SAANZ and NZSIF members.

It is acknowledged upfront that joint investment in injury prevention with ACC will be essential, as has funding for snow sports injury prevention initiatives from ACC in previous years. Once the strategy interventions get traction it is anticipated that, there will be benefits to the industry and savings to ACC in each year of this strategy. The agreed strategy is a commitment by the industry to provide resources to carry out the interventions contained in the strategy. Resources include funding

and manpower available through SAANZ, NZSIF, SSNZ and NZSIA. Funding and resource allocation will be determined annually by the respective industry organisations based on this strategy. Resource contribution will include calculation of hours of work and operational resources that will be utilised in the planned injury prevention interventions.

Participation numbers provide an indication of the size of the population that injury prevention interventions are intended to reach. Interventions with evidence of success are more likely to attract investment from partners such as ACC. The 2014 skiing and snowboarding visitation numbers were 1,380,489. The regular skiing and snowboarding population is estimated to be 203,000 participants as identified in the Active NZ Survey 2013/14 (250, 251). A positive fun injury-free experience is a win-win for all. Uninjured customers continue to spend dollars on and off the mountain in the following areas: airlines, other transport services, accommodation, adventure tourism, hospitality, snow sports equipment retail and other retail outlets. Other partners that invest in this strategy will provide added opportunities for increasing the reach of the strategy. By keeping customers safe, there is an economic value of injury prevention to ski areas and associated provincial tourism services.

For this strategy to be effective, it will require increased investment in resources by the industry and a higher upfront injection of ACC funds to support its success from 2016 onwards.

#### **7.4.6 The injury problem**

Descriptive epidemiological analyses of incident data from the Ski Areas Association New Zealand (SAANZ) registry (NID-S) for injured skiers and snowboarders treated at all commercial ski areas were compared with ACC new injury claimant data from the legislated government no-fault insurance scheme for the months 1 June to 31 October 2010 to 2014. Old snow sports injury claims to ACC were not included. SAANZ provided population numbers for each season using ticket sales and season pass records. Injuries were calculated for per 1000 skier/boarder days (see Table 7.5).

Table 7.5: Injuries per 1000 skier/boarder days

YEAR	2010	2011	2012	2013	2014
NID-S	3.19	3.33	3.37	2.72	3.08
ACC*	8.99	8.67	8.92	8.83	8.96

\* ACC data includes people first treated at mountain clinics entered into the NID-S

To fully comprehend the magnitude of the injury problem, a global perspective is needed (252). Comparison with other countries' injury trends potentially has risks as data collection may differ; however, statistical methods have been designed to support comparison, and in the context of finding solutions international injury trend and risk research is useful (51, 53, 139, 140). Norway has a central registry of 16 ski areas representing 53% of lift transport; 1.29 injuries per 1000 skier/boarder days occurred in the 2008/2009 and 2009/2010 seasons (141). The Medecin de Montagne Safety Network in the French Alps has one of the largest international snow sports injury registers, collecting data from 38 ski areas. In a case control study of 10 of these ski areas in 2007 and 2010, Laporte et al (9) found that incident rates fell from 2.77 to 2.43 per 1000 skier/boarder days. In 2006, at Sugarbush ski area USA, year 34 of a case control study, there was an overall decline in the injury rate for alpine skiing to approximately 1.9 per 1000 skier days (8). New Zealand reported injury rates are clearly higher than other countries; a possible explanation for the difference is more comprehensive national data. Some countries only report snow sports injuries that have been diagnosed by medical practitioners; and some of these injury registers may not capture all international or out-of-state injuries as people bypass mountain clinics and return home for treatment. ACC data includes diagnoses by physiotherapists and other health professionals and there is no legal or financial impediment to reporting. ACC injury no-fault cover includes: domestic, international, waged and unwaged (youth and retirees). Based on geographical location it is unlikely that injured foreign nationals bypass treatment. Given the comprehensive cover provided by ACC, injured international skiers and snowboarders may view treatment in New Zealand as more favourably than the costs of treatment at home.

NZ saw an overall decline of skiing and snowboarding injuries in 2013 (see Table 7.5). What phenomena caused this decline? Were there fewer injuries

because the snow conditions were better in 2013 than the other four years? The influence of the snow-pack on injury incidence will need to be considered and accounted for in future statistical analysis so that the effectiveness of injury prevention interventions can be separated from natural events and accurately evaluated.

Analysis of 18,382 alpine skiing and snowboarding injuries in NZ over five seasons (NID-S 2010 – 2014) is provided in the next section of the strategy; the most frequently injured body parts are identified so that targeted interventions can be determined. Please note that these interim research results are pending final research peer review and publication. NID-S descriptive results are also included in the people, equipment and environmental risk-related sections of the strategy. The researchers did not analyse raw ACC data or compare data sets for the same five-year period, ACC have provided summated results.

#### Knee

Based on prevalence, reduction of knee injury in alpine skiing is the priority. Nearly one third of NZ adult skiers injuries involved the knee; 30.2 % compared to 9.9% for lower leg injuries; this statistic mirrors the findings of international studies (8, 9, 48, 49, 61, 68, 77, 253-256). Knee injuries occurred more frequently in skiers, 76% versus 21% in snowboarders, and 3% in other activity. The longitudinal study that commenced in 1972 at Sugarbush ski area in Vermont USA provides one of the most comprehensive pictures of knee injury trends; between 1975 and 1991 the risk of sustaining a knee injury in alpine skiing that involved the anterior cruciate ligament (ACL) increased by 249% (8). Comparative analysis of 232,571 snow sports injuries undertaken by 72 French doctors in the Medecins de Montagne Safety Network in the period 1992-1999 determined that 21,303 injuries of a total of 232,571 injuries were ACL ruptures, accounting for 12.5% of the total downhill skiing injuries as compared to 0.6% of snowboarding injuries (48, 49). Females have dominated these knee injury trends since the introduction of the carving ski in 1993 (56). The risk of knee sprain is 2 to 3 times higher in females and the risk of anterior cruciate ligament rupture (ACL) is up to 9.7 times higher (48, 68, 69, 73, 77, 124, 141, 254, 257-262).

## Head

Head injuries were 11.2% of all injuries (NID-S 2010 – 2014); of these 45.4% were snowboarders, 53.2% skiers and 1.4% other. Children were twice as likely to sustain a head, face or neck injury than any other age group and terrain park users were more likely to suffer a head injury with loss of consciousness than skiers, regardless of helmet use (95, 97, 98). Head injury is a broad term that encompasses soft tissue injuries of the head, concussion, skull fracture, and traumatic brain injury (TBI) that include different cerebral bleeds. It is important to note that head injuries are not equal in terms of morbidity (102-106).

## Back

Back injuries were 17.7% of all injuries; cervical/thoracic 36%, lumbar/sacral 64%. Snowboarders were twice as likely, to sustain lumbar-sacral injuries than a cervical or thoracic spine injury (NID-S 2010 – 2014). Two NZ studies on spinal injuries provide further description on the gravity of the injuries. In the Otago spinal injury study (1991 – 2002) 18 snowboarders and 7 skiers sustained spinal injuries (62). Skiers were mostly injured in falls and snowboarders were injured in jump manoeuvres. Wedge fractures of the spinal column were the most common fracture type. A higher proportion of skiers than snowboarders had burst/compression fractures and the most frequently fractured vertebrae were found at the thoracolumbar junction at the posterior base of the rib cage. Of the 88 patients admitted to Invercargill Hospital over the 2009 winter season, 26% had spinal injuries including one C5 burst fracture which was ultimately fatal (146). The Swiss found that the majority of severe spinal injuries (n=63) admitted to a tertiary trauma centre were related to skiing, and over half of all spinal injuries had two or more levels of injury (96). In an American study, spinal cord injury was relatively rare, occurring in 0.98% of individuals and equally likely to occur in snowboarders and skiers (263).

## Shoulder

Falls that occur on an outstretched hand create direct load or excessive rotation of the arm that may lead to shoulder dislocation (264). Shoulders injuries were 11% of all injuries; commonly snowboarders, 61% versus skiers 37%; fractures of the clavicle were 3.9% of all injuries and twice as likely in snowboarders (NID-S 2010 – 2014). The prevalence of shoulder injuries increased with ability, males were twice

as likely to injure the shoulder than females, and rotator cuff tears of the shoulder joint leading to instability were common in both genders (141, 265, 266).

### Wrist

Wrist injuries were 14% of all injuries; most commonly snowboarders, 79.9% versus 17.9% skiers (NID-S 2010 – 2014). Injury trend studies in other countries have found similarly high rates of wrist fractures in snowboarding of up to a 10-fold increase in snowboarding compared to skiing (8, 50, 60, 141, 147, 148, 161, 263, 266-272). First day snowboarders are twice as likely to sustain a wrist fracture, than those with more experience, and most wrist fractures occur within the first 7 days of learning to snowboard. Observed fall directions in 679 snowboarding falls found that in forward toe-side falls there was a 66.5% likelihood of landing on the leading hand. A backward, heel-side fall had a 63% likelihood of bracing with the trailing hand (147). Understanding these fall mechanisms will be important when considering interventions.

### Lower leg

Lower leg injuries were 6.4% of all injuries; most commonly skiers 73.8% versus snowboarders 22.9% (NID-S 2010 – 2014). Prior to 2000, across the world lower leg injuries in alpine skiing were declining; lower leg and ankle fractures are unfortunately now increasing in prevalence (9, 48, 49, 206). The increase in lower leg injuries is attributed to inappropriate ski-binding settings, poor ski boot fit and changes in ski design/length. Figure 7.3 provides an overview of who was injured, what body part was most commonly injured, and how these injuries occurred (273).

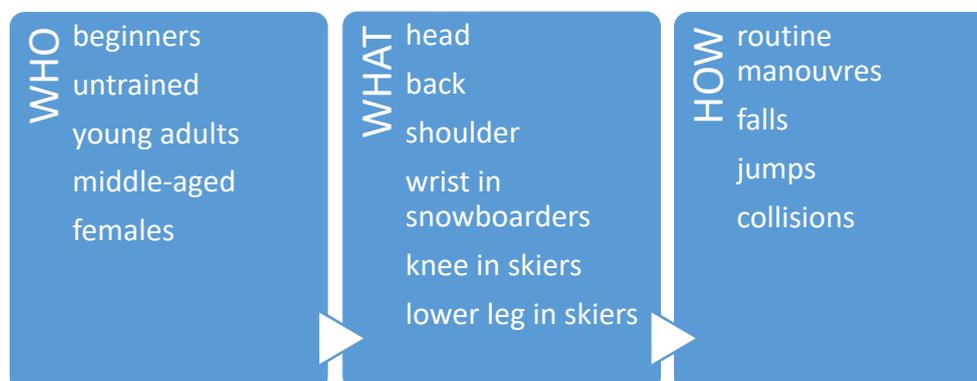


Figure 7.3: Injury surveillance overview (adapted from Kerschbaumer, 2015)

## Injury costs

Knee injury continues to be the most prevalent, and the most costly injury. In 2014, the cost of knee injuries was \$4.6 million. In the period 2010 – 2013 ACC reported that 28% of all skiing injuries involved the knee compared to 12% occurring whilst riding a snowboard. Shoulder injuries ranked second at \$4.2 million or 20.6% of total snow sport injury claims and were spread evenly across skiing and snowboarding. Back injuries were 8% of total snow sport injury claims with a combined cost of \$1.7 million. Snowboarding wrist injuries were 3% of snow sports injury claims at \$628,000 (9% of all snowboard injuries). Based on cost, approximately 90% of the ACC snow sports were deemed minor injuries. The clinical definition of minor injury may differ from a cost-based description. The following section on risk provides further detail on how and why these injuries occur.

### 7.4.7 Risk factors

Determining risk is challenged by the difficulty of capturing the actual moment that an injury occurred, the complexity of multiple factors being at play, and the challenge of determining the catalyst(s) (243, 244, 274). Ski patrollers have effectively informed the risk factor picture (52). Case control studies of alpine skiers and snowboarders have defined the difference between the population that was injured compared to the uninjured population (9, 49, 275-281); experimental studies have provided force measurements (282, 283), video analysis has provided biomechanical information (284-287); observational studies have expanded understanding of the injury moment in skiing and snowboarding incidents (147, 288); and meta-analyses have combined studies in an attempt to provide sufficient and reliable information to inform interventions (274, 278, 289-294). In summary, understanding what causes accidents is an essential step in formulating targeted injury prevention initiatives for snow sports (295).

Further analysis of the NID-S 2010 – 2014 is included on the effects of: ability, snow, visibility, equipment and time-of-day. The NZ descriptions of incident type add to the risk factor pictures garnered from international research and highlight the opportunities that exist for injury-prevention interventions going forward. The people-related, equipment-related and environment-related risk

sections are by no means an exhaustive discussion; these sections are an abbreviated treatise of main findings.

## **People-related risk factors**

Characteristics of people can influence the risk of sustaining an injury:

### **Age**

Lower leg fractures were two to five times higher in skiers under 14 years. Conversely, when comparing age group injury patterns, adult snowboarders sustaining lower leg fractures was two to three times less likely than an adult skier (206). The risk of children sustaining specific types of limb fractures (green-stick or growth-plate) relates to developmental changes of the skeleton (110, 296-302). In younger children, the head is proportionally larger than adults, this leads to the head often being the first point of impact in a fall. Children are two times more likely to sustain head injuries than adults when skiing or snowboarding (97).

Ageing is associated with loss of bone density, reduced muscle mass, and loss of ligament or tendon tensile strength and elasticity. Worldwide, falls in the elderly that result in injury are an identified health burden. Staying physically active is a recognised injury prevention strategy that can help maintain balance, co-ordination, strength and flexibility to curb the risk of getting injured in falls (23, 236). Skiing or snowboarding in most instances does not carry an associated risk of injury with increasing age unless an individual has lost conditioning and balance for the specific movements required in snow sports (29, 303, 304). Continuing to participate in snow sports could be beneficial to overall health. In skiers aged 55 years and over, the risk of mild and major knee injury was lower than younger skiers (mild < 42%, major < 33%). Older skiers had no significant increase or decrease in risk of fractures or strains when compared to younger skiers; however, the risk of tibial plateau fractures was 5.7 times higher (24, 305). The highest ACC snow sports claims in 2014 by age were skiers 40-59 years and snowboarders 20-29 years.

### **Gender**

The risk of knee injury in female skiers was 2 to 3 times higher than males. More specifically, the risk of anterior cruciate ligament rupture in female skiers compared

with males has been reported to be 2.3 to 9.7 times higher (48, 49, 68, 69, 73, 77, 83, 124, 141, 254, 257-262). The physical factors attributed to the increased risk of knee injury in sport for females were anatomical differences related to the hip and knee angle (knock-kneed), quadriceps dominance over hamstrings, and laxity of knee ligaments exacerbated by hormonal changes. ACL injury risk for females increases over 24 years of age and more than 80% of knee injuries in female skiers occurred in the first 3 hours of skiing (255, 261). Incorrect set-up ski-binding-boot systems is an identified risk factor for females (48, 83, 255).

### Vision

Visual acuity is needed for hazard identification. Visual deficiencies that require correction may present an issue when optical correction is not used in sunglasses or goggles (306). In a study of 73 recreational skiers aged 22 to 61 years correction was needed for 29% of the sample, an inability to estimate distance was found in 20%, and only 66% of the skiers that wore prescription glasses or contact lenses in daily life wore these on the mountain (163). Large, stationary or moving objects were seen, but awareness of low-contrast obstacles was compromised by restricted visual acuity. Observation and perception errors may lead to falls and collisions. Decreased visual acuity may lead to delayed reaction time and an inability to take evasive action (163-165).

### Physical conditioning

Skiers and snowboarders that undertake a regular regime of exercise, healthy diet, rehydration and rest, has been found to improve physical fitness for snow sports and may reduce risk of injury (307). Leg muscles act as shock absorbers in landing and undertake repeated significant loads during a day on the slopes which inevitably leads to a level of fatigue (261, 308-311). Snow conditions and changing terrain may force the skier or snowboarder to alter their style and increase physical demand with edge angulation, pressure distribution, changes in intensity of manoeuvres, altered radius of the turn, and changes in efficiency of movement. The movement patterns of skiing and riding affect physiological responses and may lead to muscle stress. The repetition from a training view could enhance muscle and cardio-pulmonary system capacity; however, a few days on the slopes may see little gain in snow sport specific conditioning in recreational athletes. Muscle fatigue is associated with a build-up of fatigue related metabolites, which may compromise

coordination (309, 312). Insufficient hydration may affect body fluid balance and renal excretion of metabolites (313, 314). Inadequate nutrition and poor hydration may affect performance, strength, power, stamina, and recovery time (315). Children have a greater risk of dehydration as their thirst inhibition is switched off by the developing brain before adequate hydration levels are achieved (316). Fluid loss is associated with impaired: performance, visual-motor tracking, discrimination of environmental changes, and short-term memory. Conversely, good physical conditioning is associated with postural control and improved balance, essential elements to advancing correct skiing or snowboard riding techniques and mitigating the risk of injury (303, 304, 307).

#### Previous injury

Return to skiing or snowboarding after injury with or without surgery may be associated with an increased risk of re-injury due to diminished neuromuscular control and loss of physical condition if a functional rehabilitation programme is not undertaken (204, 317). Rehabilitation strategies need to be multi-faceted and consider interventions that address physical healing and the psychological stress associated with recovery (318, 319). Ski-bindings set too high for skiers that are in poor condition could add to the risk of re-injury of the knee (83). Studies on previous injury in snow sports largely relate to knee/anterior cruciate ligament reconstruction in competitive skiers (320-323). In a small qualitative study of high school aged knee injured skiers (2 male, 3 female), only the male skiers returned to competitive skiing after reconstruction surgery (324). The males were confident in their ability after post-operative rehabilitation, had enhanced physical capability and were supported at all levels versus the females who stated that they had a lack of support at all levels (including family), deterioration in their physical ability to ski at the elite level and had diminished confidence. Life stress, low coping capacity, low support levels and a history of previous injury was associated with delays in recovery in NZ rugby union and rugby league players (35). Addressing the psychological challenges of recovery was found to reduce time lost from the game. Role-modelling using video of athletes of a similar age that successfully rehabilitated from similar injuries reduced recovery time; these techniques could be used to get injured skiers and snowboarders back into snow sports.

No negative effects were found after 10 years on the acetabular or femoral component of hip replacements when comparing 50 Swiss skiers that had hip replacements with 50 people that did not ski (325). In 2007, orthopaedic surgeons' added support for a return to skiing after 3 to 6 months for those that had experience in international post-operative guidelines, a return to snowboarding was not recommended (326).

#### Ability

Being a beginner was clearly associated with increased injury risk in both alpine skiing and snowboarding (8, 9, 206, 327-330). The issue of limited days on snow impacted on skill-retention, this placed intermediate skiers and snowboarders at risk. Only 10% of injured intermediate snowboarders received professional snowboarding lessons (331). In video analysis of expert skiers (world-cup racers) technical mistakes and inappropriate tactical choices were the dominant factors in falls (131, 284, 286). Ability to adapt technique to changes in snow conditions were risk factors for all abilities. Loss of control was mostly the domain of beginners and intermediate skiers or snowboarders (147).

#### Knowledge

Beginners are unfamiliar with both equipment and the environment; intermediate skiers and snowboarders are still acquiring knowledge of what equipment and accessories are good and gaining mileage in varying mountain conditions; and advanced skiers and snowboarders may have limited or no local terrain knowledge. Sightseeing tourists or those using sliding devices may never have touched snow and have no concept of mountain risks. Risk reduction endeavours need to constantly bolster snow sports equipment and local terrain knowledge, and living the snow safety rules (see, Appendix IX).

#### Behaviour

When designing injury prevention interventions, it is important to not adopt a one-size-fits-all view of risk behaviours. Attitude, cultural norms, and physiological state contribute to behavioural risk factors (12). Many expert skiers and snowboarders have thought through their exposure to risk when exploring personal or technical boundaries. These individuals often have honed skills and knowledge to limit the

chances of injury. In all individuals from novice to expert, changes in physiology and fatigue may affect risk-perception, decision-making, motor skill and reaction times (311, 332, 333). Overcoming fear is part of the challenge of adventure sports (334, 335). However, an individual's nervous disposition may negate the positive effects of increasing confidence. A stiff locked-up stance could lead to unbalanced manoeuvres and bracing in the fall could increase the risk of musculoskeletal injury. A drop in blood glucose due to inadequate food-intake could be a factor in behavioural changes. In some individuals, excessive alcohol intake, recreational drug use, or under/over medication with prescription drugs may affect behaviour (336, 337).

### Speed

Recreational skiing and snowboarding speeds averaged 43 km/h, well over the ASTM F 2040 helmet testing speeds of 22.6 km/h (338). The average speed for children skiing on an intermediate slope was 18.7 km/h, and in slow zones it was found that adult skiers underestimated their speed by 12 km/h. Gaining speeds over 100 km/h during recreational skiing was not uncommon (110, 228, 339, 340). The risk of serious injury when colliding with an object or another snow sports participant at speed is high. Velocity increases exposure to deceleration forces on impact with the snow surface, a manmade object, or when colliding with another skier or snowboarder. Deceleration forces lead to the contra-coup movement effects on brain tissue that contributes to the gravity of traumatic brain injury, or blunt tear and shear forces in internal chest, internal abdominal or retro-peritoneal injury involving the kidney. Ski and snowboard equipment testing, protective-equipment testing and biomechanical studies in jumps or racing contribute to the understanding of the forces that occur in snow sports (69, 109, 118, 128, 282, 283, 341-345). Research in other activities such as cycling accidents and road trauma also help understanding of speed and the effect on body tissue when a person stops suddenly (346-348). Speed has probably contributed to the anomalous effect of helmets on head injuries in the NID-S data (2010-2014).

### Risk-taking behaviour

Risk compensation occurs when people react to safety rulings by increasing risk-taking behaviour (219, 295). The risk-taking demographic identified in international studies (158, 159) is anecdotally the same in NZ: young, male and an intermediate

or advanced skier or snowboarder who perceives that they are “bullet-proof.” For example, adolescents and adults that wore helmets did not show greater risk-taking behaviours but adolescence were found to continue high-risk behaviour with or without a helmet (349-351). Risk-compensation could offset the protective value of the helmet; however, this proposition has not been proven in snow sports. The safety net of accident compensation may also add to risk-taking behaviours by diminishing personal responsibility (142, 352).

## Equipment-related risk factors

### Design

Ski or snowboard equipment needs to be an appropriate match for an individual's competence. Advances in equipment design are a double-edged sword that has improved performance and potentially increased risk factors. The revolutionary shorter side-cut ski design has made for fast lively carving turns that place skiers on a trajectory that they may not have planned for. The introduction of carving skis was associated with increased proportions of shoulder/back and head injuries and no decline has been seen for injuries to the knee (56, 63-69). Flexible skis provide latitude for body alignment issues as the ski lets the individual turn or skid. A higher performing stiffer ski is less forgiving. Edge profile changes support different radii turns that may or may not be handled by skiers developing competence. Blunt edges increase risk when traversing across icy or hard snow. Twin-tip rocker advances in snowboard and ski design have made aerial manoeuvres possible. Enhanced bending, torsion, stiffness and impact-absorbing properties have provided smoother travel at higher speeds and reduced equipment breakages. Lighter equipment and base construction has reduced resistance across the snow, helped gliding and increased speed. Different wax products support gliding in different conditions (125). No wax on bases or the wrong wax increases surface-friction and grip on the playing-surface, which may increase the risk of a fall. Ski boots with different forward lean angles, height and rigidity have protected the ankle (when fitted correctly), but potentially transferred injury forces up to the knee. Flexible rear spoilers on ski-boots designed to release in falls have been invented but the uptake has been limited (341). Avoidance of excessive loads on the knee structures (172) underpin the current mechatronic ski-binding research efforts of the Technische Universität München (TUM) and the Swiss Council for Accident Prevention (84, 124).

### Ski-poles

Ski poles are made of aluminium, graphite or composite lightweight materials that should not break. Indentation for the fingers on the handles support good grip. Recreational ski poles are straight with a hand-strap. Ski-racers ski poles are curved to reduce drag and are equipped with a pole-guard for hand protection. To get the correct length of ski pole the skier inverts the pole and places a hand under the basket and the arm should align at 90 degrees to the pole. Incorrect sized poles and loose or missing baskets could increase injury risk. "Skiers' thumb" involves

partial or complete tear of the ulnar collateral ligament (UCL), an important ligament that is needed for pinch and grip strength (353). Complete ruptures require prompt surgical repair. Poorly managed UCL tears could lead to on-going hand pain and loss of function. A pole without a basket has the potential to be the catalyst for a fall or an object that could lead to a puncture wound in the skier or impales another person.

#### Ski-binding-boot systems

The ski, ski binding, and the ski boot when combined are called the ski-binding-boot system (S-B-B); a system designed for retention or release in certain conditions. Release settings for ski-bindings are based on height, weight, boot-sole length, age and self-reported ability (90-93, 166, 171, 192, 354). Not checking current weight on a set of scales for both adults and children or confirming the new height of children and youth that are still growing on a height chart or stadiometer could lead to incorrect calculation of release settings (DIN). Cross-sectional national surveys of NZ rental technicians (n= 227) found that 32% did not check weight and 40% did not check the skiers height (355).

Skier type charts explaining skier style need to be used to accurately determine the release setting. For example, an expert skier that has had limited skiing may no longer be skiing aggressively on steep slopes and now enjoy all terrain at a moderate pace; this change in style would move the type III skier that has a comparatively high release setting to a type II skier that requires a lower release setting. The AFNOR chart provides the most comprehensive description of skier type that can better inform set-up decisions (see, Appendix IX). NZ ski technicians identified that a local version of the skier type chart is needed (154).

Ski-binding release settings (DIN) that are too tight (high) increase the risk of non-release. Premature release may occur when the setting is too loose (low); however, too tight appears to be the predominant risk issue. Incorrect set-up increases the risk of knee and lower leg injury (49, 70, 71, 82-84, 90, 92, 124, 151, 153, 154, 166, 167, 169, 171, 173, 192, 207, 212, 354, 356-361). Lack of regular ski-binding-boot system inspection; poor maintenance of edges and bases; ill-fitting ski boots, ski-boot wear and tear that compromises ski-binding retention (an issue in NZ when skiers walk in ski-boots on unsealed access routes to get to the slope);

worn anti-friction plates compromised by pitted worn ski-boot bases leading to increased friction that may limit release; and no regular torque-testing with a calibration machine or torque wrench to check the efficacy of the spring and lever system all add up to not meeting international equipment safety standards (90-92, 153, 166, 167, 190, 207, 361, 362). As per ISO 11088 and ISO 13933, a Class III deviation of more than 45% from the reference moment requires corrective action. If the corrective action fails to bring the ski binding to within 15% of the reference moment, permanently retiring this equipment from service is the logical safety decision. In NZ access to torque-testing services are extremely limited. Annual torque testing of the ski-binding spring and lever system and tuning is a strategy used by the Swiss Council for Injury Prevention. One million torque-test stickers are issued by Swiss ski technicians each year when private ski equipment is serviced (240). International ski equipment testing standards have also been fully adopted by EU countries, the USA, and parts of Canada. German and North American insurers drive safe equipment initiatives by requiring evidence of recent equipment testing to support injury claims. Rental shops in these countries torque test all stock pre-season and sample test during the season as per ISO 13993:2001 (E) (90). In a NZ study looking at ski rental equipment risk (151); heelpieces that had two or more seasons of use were nine times more likely to be out of tolerance when machine torque-tested than those with only one season of use. Torque testing helps rental outlets make informed decisions. Class II deviations require immediate servicing. Only 8% of the rental fleet had class III deviations warranting removal from the rental fleet.

The unpublished findings of the 2015 ski-binding release study of privately owned ski equipment using torque-testing indicates that over 30% of equipment did not meet international safety standards. The efficacy of the self-release manoeuvre was also compared with machine torque testing. Interim findings are that the release setting for a skier that uses the self-release manoeuvre did not match the recommended ISO values (86) and was not a manoeuvre that all skiers could do. The only way to reduce the margin of human error to correctly set-up the ski-binding, check the accuracy of the release indicator at the toe and heelpiece, and determine the effect of age on the ski-binding spring and lever system is to use a torque-testing machine such as the Montana Jetbond or the Wintersteiger Speedtronic or use a Vermont Torque Wrench (151, 355).

## Boot fit

Good ski boot fit correlates with good technique and limits the risk of knee or lower leg injury in at risk groups. The Mondopoint system is used for sizing ski-boots, a measure of the sole of the foot in centimetres (363). The Brannock foot-measuring device helps to accurately determine the size. In an unbuckled boot the big toe should touch the front of the boot with approximately one to two fingers spacing between the lower leg and the back of the boot. Once buckled the ski boot provides stability to the ankle and the effect of closing the buckles creates sufficient room for the toes to move. For any skier a comfortable boot will ensure that they are not mentally fatigued by discomfort. Hip adduction and knee abduction (valgus) is an alignment issue that may affect a skier's ability to engage and hold a carving edge; also knee joint-loads are altered (66-68, 175, 364, 365). Valgus alignment results in a knock-kneed A-frame position and is often seen in female skiers. Reduced flexion at the ankle may also affect stance. Limited range of motion in the knee and ankle to increase the angle of the ski edge may cause rotation in the hips and the upper body. The compensation of over rotating may place the skier up-hill at the end of the turn, unable to link into the next turn, and off balance. Anatomical alignment issues can be addressed with boot modifications that make the ski lie flat without strain in a neutral stance. Expert boot fitters custom make foot-beds, adjust the boot-liner and cuff, modify the shell, and cant the boot by building up the angle of the boot-sole. Correctly fitting ski boots in rental settings is potentially challenged by large numbers, limited or no measuring devices, the time intensity of boot fitting and the desire of skiers to quickly get out on the slopes.

Snowboard boots have three types of shells: soft-flex, medium-flex and hard shell. Hard boots have lean adjusters to enhance turning power and are ideal for alpine racers but have limitations in terrain parks and are not suitable for most snowboarders. Recreational riders need boots that fit well, are not too soft or too stiff and provide stability. Squeezed snow-boot material when ratcheted down in the binding equates to a bad fit. Boot rigidity has been found to affect calf muscle activity in turns (30). Good snowboard-boot fit correlates with improved riding. In aerial moves, good heel hold is essential; to that end, some boots have heel straps or lacing.

## Snowboards

Snowboards are typically constructed of five layers, with the core material determining the overall weight, flexibility and strength of the board (127). The foam construction of lower-end snowboards results in a more flexible weak board that may not take all manoeuvres and can increase the risk of injury if the snowboard breaks on landing after taking big air. Snowboards may also have a convex base from toe to heel edge. Beginners require equipment that has a softer torsional flex, bevelled edges, is not overly cambered and a medium to short length. The design of the beginner snowboard reduces the chances of the downhill edge catching. Beginners should not step-up too quickly to stiffer boards; the recommended time on a beginner board equals 7 days or more. The torsional stiffer snowboard opens up all terrain riding and the required advancement in skills. Poor maintenance of snowboard edges and bases could compromise turning ability and travel across different terrain. Snowboards have non-release bindings, no brakes and the leg-rope feature seen with surfing is not commonly used. Snowboarders that remove the board to walk have an increased risk of injury, as snowboard boot soles may not be suited to the slope angle or snow condition. The risk of a runaway board and striving to retrieve the board adds to the risk of serious harm. The lack of a snowboard brake as a safety feature is a design deficiency that needs to be addressed by snowboard manufacturers (366).

## Sliding devices

Toboggans/sledges or tubes attract risks that are associated with steering difficulty and no restraint or braking device. The body mass of an adult and child riding together on a toboggan/sledge was found to compound speed and force leading to serious injury (206, 296-302, 367-371). Tubing injuries at ski areas in New Zealand were 1% of all injuries in 2010, this halved in 2013 and rose slightly to 0.65% in 2014 (NID-S 2010 – 2014).

## Helmets

Helmets limit linear acceleration by no more than 300 g following a 2.0 m drop onto a steel surface (translating to 27.7 km/h) with the protection afforded by the helmet declining over 300 g's (109). To achieve international snow sports helmet standards (RS 98, F 2040-06, and EN 1077-07) rigorous product testing occurs (42, 107, 108); helmets that meet these testing standards became the requirement/rule for

all FIS races in 2015. In simulated testing helmets provided good protection in hard snow impacts, with a reduction of head accelerations in the order of 48% (283, 372, 373). Conversely, in soft snow headfirst impact testing using a Hybrid III testing device, head accelerations with or without a helmet were low. Snow sport engineering and biomechanics researchers continue to investigate dynamic impact, the suitability of materials and the design of helmets to optimise protection of the head (283, 374). Hearing capacity may be dampened by a helmet in frequencies 2–8 kHz (42, 108, 375). Replacement is indicated if a helmet is damaged, as the materials may no longer have the integrity needed to offer protection to the head. Mounting a camera on a helmet may also affect the integrity of the shell if the camera is not mounted in a headlamp position as per the manufacturer's specifications. The protective affect of helmets also reduced when young skiers or snowboarders modify helmets to fit beanies and leave the clip undone when not riding in the terrain-park.

Helmets have been found to reduce the incidence of head abrasions, lacerations, and mild concussion in snow sports (111, 112). Results vary on helmet risk reduction of head injury from 28% to 60% (97, 101, 110, 111, 289, 376). That is, for every 10 people skiing or snowboarding who wear helmets, three to six may avoid head injury. Importantly, wearing a helmet was found not to increase the risk of neck injury (155). Wearing a helmet in icy snow conditions was estimated to reduce the probability of a skull fracture and severe brain injury from approximately 80% when not wearing a helmet to 20% (109). There was a slightly lower rate of helmet wear in brain injured skiers compared to the Swiss general snow sports population; 71% not wearing helmets and 81% wearing helmets (64, 377). Brain surgery was required in 28 of these skiers and 5 snowboarders. Of the 5 snowboarders that required surgical intervention for cerebral bleeds, only 1 of the 5 was wearing a helmet (377). The damping effect of the helmet may reduce the severity of the head injury (348, 373, 377-379).

There is some evidence that helmets do not always protect against traumatic brain injury. Despite increased helmet use in Switzerland by skiers (14% in 2002/03 to 87% 2013/14) and snowboarder helmet wearing increasing from 10% to 69% there was no decrease in severe traumatic brain injury (64, 377). Skiers with brain injuries were 18% of all skiing trauma (245/1362) and 17% of all snowboarding

trauma (117/691). Skiing off-piste or away from prepared slopes was associated with increased risk of severe traumatic brain injury; it was concluded that snowboarders may have a false sense of security and take more risks when wearing a helmet. In a recent review of the Swiss study on the association between head injury and helmet use in alpine skiers; ski patrollers and mountain clinic staff were reminded to consider traumatic brain injury regardless of helmet or no helmet (64, 380). In preliminary analyses of the NID-S (2010 – 2014) for head injuries sustained in terrain parks, a clear small but substantial harmful effect was found in skiers and snowboarders who wore helmets and sustained head injuries when compared with other injuries that occurred in those wearing helmets: 26% increase in risk (99% confidence limit, CI 11% to 42%). This unpublished finding (Costa-Scorse, Hopkins, Cronin, & Bressel) also raises concern that risk compensation when wearing a helmet is occurring in New Zealand (please note this manuscript was accepted after publication of the strategy).

Overall, given the increased risk for receiving various types of head injury, when not wearing a helmet skiing or snowboarding and the potential benefits of damping the forces transferred to delicate brain tissue, using a helmet should be encouraged (95, 104, 105, 289, 376, 381-383). However, more research is required to understand why some skiers and snowboarders who are wearing helmets are still getting head injured. Going forward, the baseline data and the annual helmet/bare-head counts in this strategy are absolutely essential to monitor the effect of increased helmet use.

#### Snowboarder wrist protectors

Snowboarders may utilise wrist protectors (commonly referred to in NZ as wrist-guards) to reduce the risk of sustaining a wrist injury. Snowboarding wrist injuries often involve fracture of the radius and ulna proximal to the wrist joint (147). Using the correctly designed wrist-guard may reduce the incidence of wrist injury by 38% to 68% (148, 268, 270, 272, 384). The long wrist-guard limits the compressive load and hyperextension at the wrist at impact; however, the short wrist-guard may either have no effect or be a hazard in the mechanics of injury. Currently there are no international standards available that define minimum requirements and describe appropriate test procedures for snowboarder wrist protectors. The first meetings of

ISO/TC 94/SC 13/PG ISO 20320 «Protective clothing for use in Snowboarding - Wrist Protectors - Requirements and test methods» occurred in Europe in March and June 2015. A wrist protection intervention in NZ should be based on the design specifications determined by the ISO technical committee.

### Eyewear

Snow and glare may cause acute eye injury if no sunglasses are worn or the eyewear has inadequate UV protection(306). Protection is also needed for lips and the skin (385), along with an awareness of the risk of incorrectly applied sunblock solutions running from the forehead into sensitive eyes. Snow-blindness may occur when eyes are unprotected in blue sky, cloud covered conditions or when snow is falling. When the visibility is poor, warm coloured lenses (yellow, brown and rose) improve perception and cool colour lenses (blue and grey) do the opposite, reducing contrast sensitivity and focal depth (306). Wearing the wrong colour lens for the light could increase risk of injury (163, 164, 386). Goggles may impede peripheral vision and fog-up; advances to counter fogging include vents, double lenses and anti-fog coating. Skiers and snowboarders who wear prescription glasses or contacts need to be made aware of the snow sports eyewear advances that support good visual acuity on the snow with over the glasses goggles (OTG) and tailored inserts (306). Age-related maculopathy and deterioration of sight due to excessive exposure to harsh sunlight has been identified as a risk in summer but has not been explored in southern hemisphere winter environments (387).

### Other equipment

Using a brace after anterior cruciate ligament reconstruction did not restore normal knee biomechanics, protect the operated knee or improve outcomes in the long-term (388). In a small pilot study it was established that some knee braces were found to worsen balancing ability when worn with ski-boots (389). In summary, the influence of knee braces on knee joint injuries is not yet clarified; the restriction on freedom of movement and changes in skiing behaviour may lead to adverse effects (124).

Previous injury could be a trigger for skiers and snowboarders to start wearing back protectors. Wearing body armour to absorb minor shocks has little traction in terms of population-based injury prevention measures; however, back

protection, hip padding and the padding of other bony prominences may be warranted for competitive or extreme skiing or snowboarding. Building competence with education on aerials and jump manoeuvres, should be a priority strategy rather than just “suited-up”. Further investigation on the psychological processes influencing the use of protective equipment is required (96, 390).

Listening to music was not found to increase numbers of skiers injured but distraction by music was a factor in the severity of injury in snowboarders (391). The literature on best clothing layers for the mountains and backcountry equipment were not examined.

## Environment-related risk factors

### Terrain

Not surprisingly, falls were the most common injury mechanism in skiing and snowboarding; collisions with a skier or snowboarder or a manmade object were less common (see Figure 7.4).

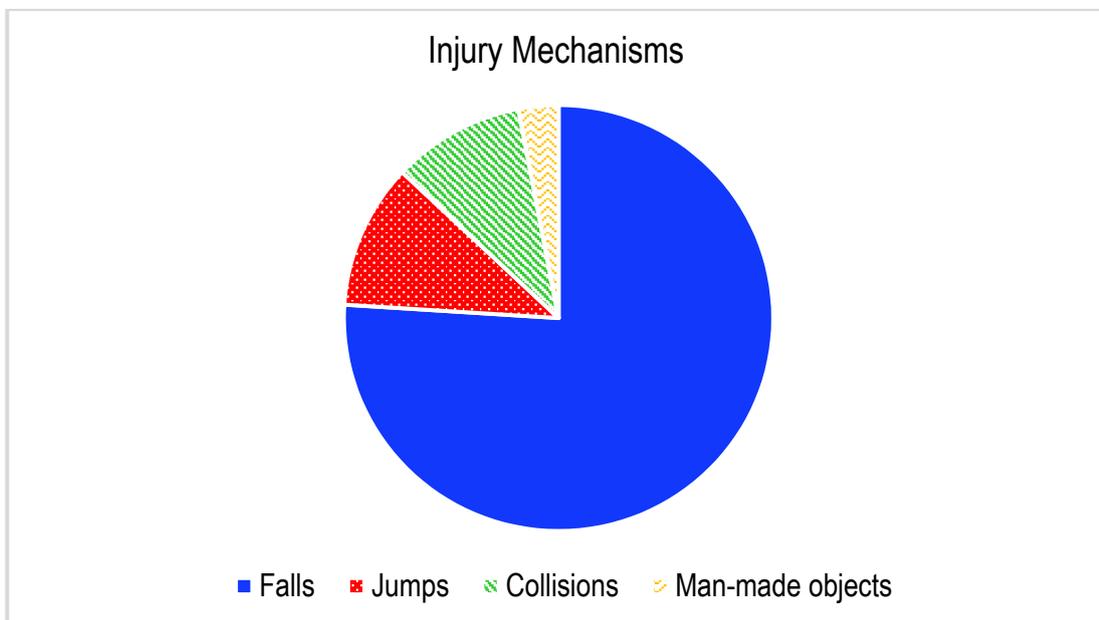


Figure 7.4: Injury mechanisms for skiing and snowboarding (2010 – 2014).

Man-made objects included lifts and terrain-park features. Ski area design has evolved at a similar pace to snow sport equipment design; where possible trails are self-explanatory, intersecting trails are devoid of blind spots, trails flow, and congestion is managed (300, 392). NZ topography and the location of some ski areas in the Department of Conservation estate may challenge SAANZ operators' desire to build wide-open forgiving trails; obstructing rocky outcrops mid-trail that are a potential hazard simply cannot be modified or modification is not permitted. Notwithstanding the many challenges of the mountain environment, a lot of work has already gone into improved trail and lift infrastructure at NZ ski areas. The natural environment cannot sustain a safety sign or barrier on every cliff band or chute. For many that recreate in the mountains exploring the natural beauty of the terrain unencumbered by multiple levels of protection is part of the culture. Where possible trails lead the skier or snowboarder on, rather than a sign advising of every nuance of the terrain. Permanent fences, tower padding, and snow berms (snow embankments) are three types of a defence used to prevent injuries. Berms require

regular attention by groomers and trail crews. Groomers work hard overnight to return trails to relatively smooth surfaces. Grooming relies on having enough snow to move around or making snow to accommodate seasonal changes in snowfall. Inappropriate trail design and poor grooming was associated with 27% of injuries at a Norwegian ski area (393). Trail merge areas require extra vigilance (392). Increased mapping of injury hotspots will help expand understanding of areas where injuries are concentrated, help mitigate risk and ensure that trail design solutions and maintenance continues to evolve.

Standardised pictorial signs (see, Appendix XI) recognised by all cultures from a distance should be strategically placed to prevent injury (394). Increasing skier and snowboarders respect for others sharing the slope is embedded in the slope traffic rules i.e. give way to those below. When merging, skiers and snowboarders should also look up to mitigate the risk of colliding. Placement of movable signs should be revised in the daily safety routines of ski patrollers and trail crews, along with use of fluorescent dye, wands or arrows when the visibility drops (providing extra help to get off-the-hill when the ski area closes early due to deterioration in the weather).

Ski patrollers make complex decisions to open and close trails based on the state of the snow-pack. Large amounts of riming ice on chairlifts and surface lifts, or excessive loading of new snow that has increased avalanche risk make for complex conditions to manage that may lead to a late or no start (395). With advances in equipment design and slope maintenance, skiers and snowboarders go higher on the ski area earlier. The challenge is that the trail may not be a good match to ability. The firmer the snowpack and the steeper the incline the higher the potential speed.

## Weather and visibility

To produce snow inclement weather is an essential part of the mountain weather picture. Inclement days are possibly easier to read, sufficient layers of clothing are needed to prevent cold-related injuries, and wearing good goggles is required to protect the face from falling snow crystals plus improves visual depth perception. Poor weather was reported by NZ adventure tourism operators as the highest risk factor across adventure activities, this study included snow sports (396). Ski areas manage poor weather risks by closure or limiting the facilities that are operating. Flat light, low-visibility, or no visibility conditions increase the risk of vertigo. Vertigo may be due to inner ear over stimulation and mismatch of the sensation of travelling over uneven ground when the horizon is hard to visualise. Symptoms of nausea and fear may escalate the symptoms of ski sickness (similar to sea or car sickness). The net effect of white snow merging with white sky is loss of balance (264, 397). Skis or snowboards hitting undetected snow mounds in white-out conditions will catch even the most experienced individual and falls may occur. The likelihood of injury was 2 to 2.5 times higher in good visibility when compared to flat light with increased cloud cover or reduced visibility in white-out conditions (NID-S 2010 – 2014). The increased blue-sky injury risk was possibly due to increased numbers of skiers and snowboarders of varying abilities on similar trajectories on the slopes and falls that occurred avoiding others. On poor visibility days, the risk of injury was probably reduced by skiers slowing down to determine contour changes and the best route, and lower participation numbers. Blue sky days in the mountains are deceptive (385); people may have insufficient ultra-violet skin protection to stop sunburn (ears, face, under the nose to counteract the burning effect of sun reflection on snow, the neck, and arms on spring t-shirt wearing days). Skiers, snowboarders and sight-seeing tourists may also be unprepared for sudden weather changes and have insufficient layers of clothing for drops in temperature (12). Wind-chill will affect even the hardy skier or snowboarder that is well dressed.

Cold conditions may also negatively impact decision-making and physiology. Only 3 cases of hypothermia (body temperature below 35 degrees) and one case of frostbite were reported over 5 seasons (NID-S 2010 – 2014). The number of cold-related injuries could climb steeply if a ski area had to undertake a full lift evacuation on a cold day. Wind will also be a factor in closing chairlifts. It is important that skiers, snowboarders and day-trippers are aware of the risks of

mountain weather and that people are tuned to the cues that changing conditions may affect skiing or snowboarding down to the base of the ski area. Deterioration in the weather also needs to be considered in accurate timing for the drive down the mountain access road.

### Snow-pack

Gliding over snow with ease is essential to ski or snowboard effortlessly. Changes in the snow-pack affect the kinetic friction created by the load of the skier or snowboarder and the polyethylene base of the ski or snowboard (398). Understanding snow surfaces is integral to maximising performance of equipment. Snow is a crystalline latticework in which the shape of the crystal, water content, ice layers and temperature determine bonding, stability and surface friction (119, 399). The snow-playing surface may become part of the injury risk equation (see Figure 7.5). Most injuries occurred on hard snow-pack. Skiers and snowboarders need to adapt their technique to the various snow conditions, which may range from perfect powder to heavy wet soft snow, hard pack, or ice. To reduce drag on the snow surface, ski bases need wax (125). Ski patrollers utilise snow science expertise to determine whether the snow surface is suitable for skiing or riding. The stability of the snow pack is also checked as part of the avalanche control process (395). Snow surface and snow pack stability information helps operational decisions to open or close the ski area or limit use of some trails. Communicating changes in surface snow conditions, snow-pack stability, and weather information to an enthusiastic snow sport population who just want to get out there, or stay out there is not always an easy task. Skiers and snowboarders often see the playground and are not cognizant of the risk, regardless of the signs and the forecast.

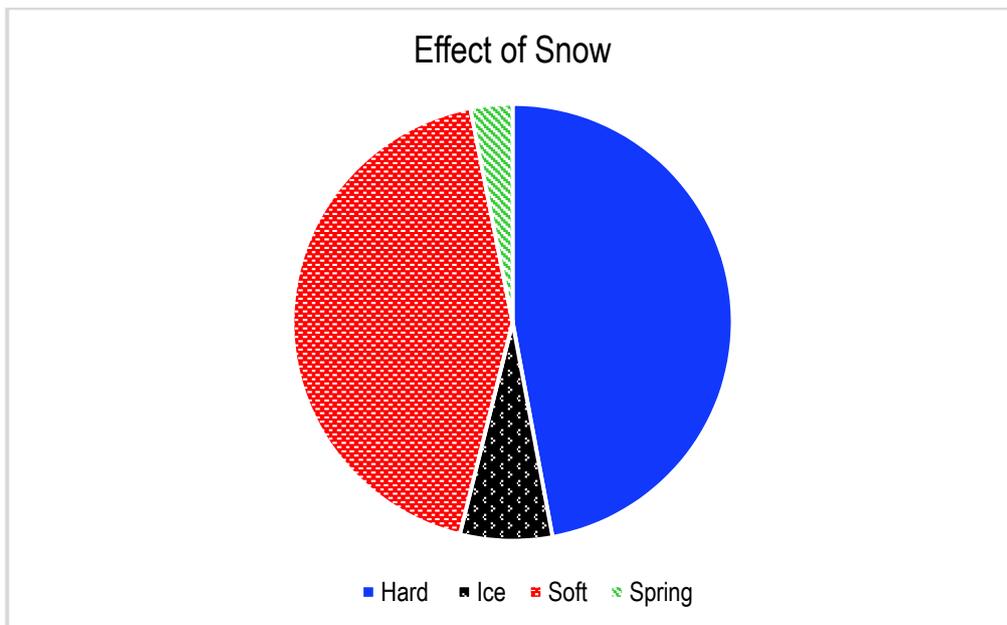


Figure 7.5: Effect of snow on injury incidents (2010 – 2014).

### Altitude

Compromised physiology due to the effect of altitude maybe a factor in poor decision-making that leads to accidents. The lowest NZ ski area base facility is 1,200 m above sea level and the highest ski area elevation is 2,322m. Altitude sickness generally does not occur below 2,500 m. However, given elderly sight-seeing tourists have often travelled from sea level to NZ mountains, altitude sickness should be considered as a reason for lethargy, faintness and falls in this at-risk group (400). Acute cardiac syndromes should also be considered as a trigger for a fall. For sedentary skiers and snowboarders that are aerobically unfit the altitude at the top of ski lifts may also be a factor in exhaustion, particularly at the end of the day.

### Time of day

Female skiers were found to be at greatest risk of sustaining a knee injury in the first 3 hours (311), no association was found with fatigue in the study of 68 female skiers. Daily counts from each ski area are needed to determine anything meaningful on the affect of time of day on fatigue. Detail from injured skiers and snowboarders on the number of hours they have actually been active on the slopes as opposed to waiting in lift lines, resting part-way down a slope, or refuelling also is required.

## Terrain parks

In analysis of NID-S 2010-2014 terrain park injuries, 69% of injuries occurred in jumps, 16% on boxes and 15% on rails (n=930). Jump-related injuries were 11% of the overall reported injury mechanisms in ski areas. To enhance performance and prevent injury a graduated approach is needed to mastering terrain park features. Signs reading: “start small and work your way up”; “look before your leap”; “make a plan”; “easy style it”; and, “respect gets respect”, reinforce the need for a staged approach (401). As evidenced in both the analysis of incidents assessed and treated at NZ ski areas and in the international research literature, jumps in terrain parks present a greater risk than routine manoeuvres (12, 149, 345, 401-403). There are a multiplicity of factors at play in jumps: speed, angle of the approach, the table-top and lip, movement patterns, type of equipment, take-off stance, pop, the type of aerial manoeuvre, landing stance, landing curve, force of impact, and the length of the run off. Trajectories from the take-off jettison skiers and snowboarders to dangerous fall heights of over 1.5 metres. The psychological factors of pushing the boundaries spurred on by social media whilst attempting to emulate the moves of experts adds to the complexity of these risk factors. Analysis of the design of jump features with calculation of the fall-height is needed to mitigate risk, along with a step-up skills programme (149). A graphic representation of ski area risk factors is provided in Figure 7.6. The intrinsic risk factors of age, gender, and previous injury should also be considered when reading this summation of risk factors.



Figure 7.6: Overview of ski area risk factors (adapted from Haddock, 1993).

#### 7.4.8 Financial Impact

The cost to ACC for skiing and snowboarding injury claims in 2014 was \$20.3 million (excl. GST), equating to 4.5% of the ACC sport and recreation injury claims. Snow sports injury costs were more than Rugby League but considerably less than Rugby Union, \$14.5 million and \$70.5 million respectively. Soft tissue injuries accounted for 77.5% of the new claims; fractures and dislocations were 12.5%. Proportionally most claims, 91.5% were ‘minor’ medical claims only rather than weekly compensation. The average minor medical claim was \$378. The cost of weekly compensation for loss in earnings in 2014 was \$6.6 million or 32.5% of total active snow sport claim costs. Weekly compensation claims with a diagnosis of concussions/traumatic brain injury (TBI) cost almost three times as much as

fractures/ dislocation or any other diagnosis. The TBI figures provide a fiscal picture of the long road to recovery for head injured skiers and snowboarders. ACC unfortunately do not gather data on helmet wear so no association can be made between protection or lack of protection and length of recovery time.

Skiers aged 10-19 and 45-49 years were more commonly injured, with skiers aged 40-44 years being the highest cost group, possibly due to this age being at peak earning capacity. Snowboarders aged 15-29 years were more commonly injured, with 20-29 years being the highest cost claim age range.

The combined skiing and snowboard regional breakdown for active ACC claims 2014:

Otago	\$6.5 million
Canterbury	\$2.8 million
Ruapehu	\$5 million
Auckland*	\$1.3 million
Overseas	\$1.2 million.

\*It is not known which ski area Auckland residents were recreating at when injured.

#### Injury reduction goal

The goal of this strategy is to reduce the injury rate by 10% over the next 5 years as indicated by ACC skiing and snowboarding claims of < than 8 per 1000 skier/boarder days. A sustained downward injury trend in the NID-S data to < 2.5 per 1000 skier/boarder days is desirable. No deaths would be a more than reasonable goal; however, due to human fallibility and the unpredictable challenges faced in mountain terrain this may never reach zero. As in all previous years of ski area operations in New Zealand, no deaths will continue to be actively pursued. Reduction of serious injuries that may result in permanent disability or a protracted recovery time of greater than three months is also embedded in this injury reduction goal.

#### 7.4.9 Pre-implementation

Prior to set-up and implementation of injury prevention initiatives an understanding is needed of the following:

- the infrastructure capacity
- the status of NZ equipment and the standard of servicing
- safety behaviours of the NZ skiing and snowboarding population

Answers to the following questions provided baseline data in 2015

#### People-related

- I. What barriers potentially exist to the uptake of injury prevention measures?
- II. Do ski areas have a compelling economic case for injury prevention activity?
- III. What education on hazard awareness do skiers or snowboarders currently receive?
- IV. Is the snow responsibility code well known, understood and applied?
- V. What speed do skiers or snowboarders routinely travel at?
- VI. Does speed create increased risk for all levels of ability?
- VII. How many skiers or snowboarders in the uninjured and injured population have had recent lessons?
- VIII. What are the fitness levels of the uninjured and injured population?
- IX. Do skiers and snowboarders place themselves at risk with insufficient food and fluid intake?
- X. Is there any physiological restriction (excessive alcohol intake, recreational drug use or under/over medication with prescription drugs) commonly observed in the injured population?

#### Equipment-related

- I. What proportion of skiers and snowboarders wear helmets?
- II. Do the helmets worn meet international standards (42, 108)?
- III. Do rental shops have sufficient stock to always supply helmets?

- IV. To ensure efficacy of the protective equipment are helmets commonly replaced every 5 years or when damaged?
- V. What proportion of snowboarders wear wrist-guards?
- VI. Do rental shops have sufficient stock of long padded dorsal or long sandwich type wrist-guards in stock?
- VII. Do rental shops always supply wrist-guards to learner snowboarders? Do they operate on an opt-in or an opt-out policy?
- VIII. Are ski-binding-boot systems (owned or rental) torque tested annually, maintained and correctly set-up in line with international standards (90, 92, 93, 167, 207)?
- IX. Are ski-boots sized correctly in keeping with international standards to mitigate risk of fracture from loose fitting boots (168, 363, 404)?
- X. Is excessive wear of boot-soles a common issue that may reduce compatibility with the ski-binding and effect release?
- XI. Are anti-friction plates on the ski-binding in-situ and functional?
- XII. Are snowboard binding mounting screws tight, edges sharpened and bases repaired when needed?
- XIII. Do skiers and snowboarders use wax that is suited to the snow conditions?

#### Environment-related

- I. Are mountain signs easily interpreted?
  - I. Is there regular accessible information on runs open or closed?
  - II. Is there regular accessible information on weather, visibility and changes in the snow-pack?
  - III. Is there information on the best wax for the snow condition?
  - IV. Is there surety that information on risk of avalanche in areas accessed by and adjacent to ski areas known and understood?
  - V. Is there regular accessible information on the status of access roads to inform safe driving?
-

#### 7.4.10 Development of interventions

Safety at ski areas involves active measures by skiers, snowboarders and all of the other people that are out to enjoy the day hiking, climbing, tubing or taking a scenic chairlift ride (refer Table 7.6).

Table 7.6: Essential behaviours for staying injury-free on the slopes

- *a personal connection and active engagement with the snow safety rules*
- *constantly making good informed decisions*
- *speeds adapted to ability, conditions and slope congestion*
- *relaxing and going with the fall rather than fighting to stay upright*
- *a commitment to reducing falls and improving skill level through professional lessons*
- *awareness of the potential for sudden changes of: incline, trail-width, snow-pack, weather, visibility and numbers of people on the same slope*
- *protective skin cream to counter the harsh effects of sun, reflection, wind and snow-crystals*
- *an understanding of food and fluid requirements to reduce the risk of fatigue*
- *appropriate clothing layers to cater for drops in temperature, falling snow or rain*
- *wearing a helmet to protect the head*
- *wearing a wrist-guard in the first 30 days of snowboarding to prevent a wrist injury*
- *buying (or renting) equipment matched to skill level*
- *ensuring equipment is maintained with sharps edges, smooth bases and wax suited to the snow*
- *annual ski-binding torque tests to check accuracy of set-up and binding function*
- *aerobic fitness that helps meet the dynamic demands of snow sports*
- *snow-sport specific physical conditioning that improves balance on skis or a snowboard*
- *neuromuscular control and agility to cater for changes in slope contour, snow conditions, changes in the light and reduction in visibility (with vision supported by good eyewear)*
- *snow-sport specific flexibility and strength training (particularly of the core) so that the back and other muscles of the body are not strained*

Active measures are about taking personal responsibility to remain injury-free, as opposed to passive measures such as an air bag in a car deployed on impact regardless of the person driving (5, 6, 383).

#### Communication

Good communication with the customer base is a foundation for effective ski area safety management. It is well accepted by psychologists that the human brain must be exposed to messages multiple times before a change in behaviour occurs (13). Effective public communication begins well before the visit to the ski area and must employ multi-media channels that are relevant to the audience. It is also important to recognize that *quality* messages are more important than *quantity* and that they should be relevant to the customer at the time they receive them. National injury prevention campaigns will provide the economy of scale and power needed for important messages that will need to be retold time and again. By repeating themes in bite-size digestible format all ski areas will work in a cohesive way to reinforce desired behaviours.

#### Addressing the risk triangle

Education interventions cannot be singular and need to consider the three sides of the risk triangle: people, equipment and environment (12) (see Figure 7.6). For example, a helmet intervention needs to be undertaken in tandem with an education intervention for people skiing and snowboarding in control. Increased equipment knowledge is needed so that skiers and snowboarders are aware that impact forces in falls or collisions at speed may out-weigh the protective capacity of the helmet. An environmental understanding is also needed so that skiers and snowboarders are aware that head impacts on hard snow-surface even when wearing a helmet may result in concussion/traumatic brain injury. It is important to reconnect with the head and helmet risk factor sections of this strategy when designing interventions and reinforce understanding that all head injuries are not equal in terms of morbidity (102-106, 116). Hard knocks increase the risk of traumatic brain injury; this reality leads onto education on the importance of getting checked out on-the-day by ski patrollers or mountain clinic staff to determine whether there are any signs of concussion. The connection needs to be made by people that the concern is hitting the head may injure sensitive brain tissue. Injury prevention messages need to connect skiers and snowboarders to the gravity of

brain injury which could change their capacity for daily living, affect concentration, lead to loss of stamina, reduce capacity to study or work, change personality, change ability to relate to others, and at the worst end of the spectrum threaten survival (18, 105). Heads of Safety Services and senior ski patrollers surveyed online during the development of this strategy commented that current injury prevention messaging is “too tame”. Suggestions were made that “shock and awe” strategies were needed so that the skier or snowboarder reading, listening or watching the infomercial (on head injury) makes a personal connection and changes behaviour. Messages to “wear a helmet to protect your head” could notch up to “wear a helmet to protect your capacity to function, think, and dream (big)” featuring a skier or snowboarder that is faced with the challenges of rehabilitation. There is a potential tension between marketing strategies that encourages people to ski or snowboard and injury prevention messages that could discourage participation. Whatever the message, wearing a helmet and slower speeds in congested areas need to become the cultural norm for all ages and nationalities (36, 228, 340).

### Environmental knowledge

Knowing what is needed to be safe and injury-free starts before getting to the slopes. Many foreign tourists enjoy NZ ski areas; smart injury prevention communication is required to overcome language and cultural barriers. Being prepared mentally involves environmental education and ownership of the snow safety rules. Signs at ski areas are there for peoples' safety, signage needs to be obeyed. Considering others and sharing the slope ensures that all skiers and snowboarders are afforded the opportunity of a great ride. All people that recreate in the mountains are reliant on good guidance as individuals may not know what they do not know, be partially informed, or relying on out-of-date knowledge (12, 13). Mountain weather and the snow-pack are changeable. Understanding the mountains in the context of a playground is about inspiration, humility and respect. Those who recreate in the mountains need to understand this unique environment and adapt their behaviour accordingly to mitigate the risk of harm. In reviewing the weather map before heading to the slopes people need to understand when snow will be dumping, when access roads may be icy, that black-ice cannot be seen, shaded areas of the road have increased ice risk, the access roads may close at some point in the day, definitely layers of clothing will be needed, along with a helmet and a good set of goggles that do not fog and keep out the snow crystals. Enthusiasm to get one more run in before the weather closes-in or head out-of-bounds exposes skiers, snowboarders and rescuers at risk. Education on the environmental factors that inform operational safety decisions will help to bridge any misinterpretation.

### Physical preparation

Most people get fit aerobically for the mountains by running or cycling. The movement patterns in skiing and snowboarding differ greatly from afore mentioned examples; turning a ski or snowboard, taking up the impacts of moguls, or jumping off a lip onto the slope below, places unique demands on peoples' bodies. It is important that pre-slope fitness regimes are snow sport specific (304, 307). For recreational skiers and snowboarders in sedentary or moderately active jobs the concept of training is often shelved for getting fit on the snow; such habits and attitudes probably bolster the ACC minor injury claims. Pre-season and in-season off-the-hill training needs to capture the movement patterns and motivations of enjoying injury-free skiing and snowboarding. Pro-ski simulators, wobble boards and

Bosu balls are useful tools for any personal trainers that are working on improving movement coordination (405). Endurance training to increase aerobic power and exercises that increase lower leg muscle strength should also be encouraged (406).

#### Targeted physical preparation

Tailored flexibility, strength and conditioning programmes are needed for female skiers to reduce the number and the severity of knee injuries (407, 408). A female skier programme needs to consider the issues of the knock-kneed A-frame impact on skiing technique. Advanced boot-fitting, appropriately lowered torques (lower DIN) in the ski-binding release set-up that are machine measured, and biomechanical analysis are also warranted (49, 83). Youth development coaches and parents need to consider physical limitations, in particular the age a skier moves to a race binding, as the release settings are higher than recreational ski-bindings. Most race-binding release settings (DIN) start at 8.0, a setting that is used by expert recreational skiers over 85 kg (258). Return to skiing or snowboarding programmes also require biomechanical assessment and an individually tailored programme to reduce the chances of re-injury. Psychological approaches may be needed to enhance coping skills, reduce stress, re-build confidence, and get injured skiers and snowboarders back to injury-free fun on the slopes (35, 409).

#### Skill acquisition

Acquiring skills and continuing to gain competence opens skiers and snowboarders up to the freedom of being capable of exploring the mountains in all snow conditions. Skill acquisition requires that individuals acknowledge what areas of their performance need to be improved. Being able to ski or snowboard in control is less likely to result in injury (29, 177, 281, 307, 323, 410-412). Snow sports instructors and expert skiers or snowboarders that are teaching others have a key role in the success of this strategy. Being able to get out of difficult situations are essential risk reduction skills. Kick turning on a slope to change skiing direction in hard or icy snow conditions or navigating difficult traverses with a snowboard should be the domain of all people that are taking blue square runs and black diamond runs (see Appendix XI, SAANZ safety signs). Fall techniques also need to be considered when developing interventions as trying to stay upright particularly on skis can increase the anterior drawer effect on the knee leading to anterior cruciate rupture (85). If falling, going with the falling motion (relaxed if possible, rather than

board-like) then staying down rather than trying to recover has been associated with reduction in injury. Acquiring techniques (whilst wearing wrist protection) to counter falling on an outstretched hand may also have merit, particularly for learner snowboarders (148).

#### Equipment maintenance

Interventions need to promote that skiers and snowboarders undertake regular maintenance of bases and application of wax prior to getting on the slope to ensure that equipment glides. Edges need to be kept sharp so that equipment can meet the demands of turning and traversing in different snow conditions. Education is also needed on equipment storage: during the off-season skiers should unload the ski binding at the heel and store equipment with a binding release setting (DIN) of zero.

#### Ski-binding function

Skiers put enormous trust in their ski binding; these spring and lever systems need to be torque tested prior to first use for the season. To design targeted interventions for the prevention of knee and lower leg injuries it is important to comprehend the biomechanics and loads involved in skiing (124). A dual directional ski binding that has undergone functional tests and that has been correctly set-up may offer knee protection in loads 1 – 3 d) (see Table 7.7). Release from the binding in these loads will prevent excess force being placed on the medial, lateral and anterior cruciate ligaments of the knee. Binding-release will also prevent fracture of the lower leg (tibia and fibula). A new binding design solution is needed for 3e – 4 b loads as the dual-directional binding is unloaded in these situations the binding will not be triggered to open and as such will not protect the knee. Technical possibilities to optimise the ski-binding continue to be explored (84).

Table 7.7: Critical loads during skiing that lead to knee ligament injury (adapted from Freudiger & Frederich, 2000).

<b>CRITICAL LOADS</b>	
<b>FLEXION</b>	
1a	Flexion with anterior-tibial load Landing on the ski tail Backward fall Raising from or avoiding backward lean by quadriceps-pull
1b	Flexion with enforced anterior-tibial translation Transition of sliding upper body from uphill to downhill side
1c	Hyperflexion
2a	External rotation in hyperextension or extension Upper body rotates instead of skis
2b	External rotation + anterior-directed translation
<b>MOVING DIRECTION FORWARD</b>	
2c	External rotation + valgus Ski tip turns outwards Body centre of gravity clearly in front of the binding
2d	External rotation + valgus in flexion Body centre of gravity clearly in front of the binding
2e	External rotation + valgus + anterior-directed translation Body centre of gravity clearly in front of the binding
2d	External rotation + varus + anterior-directed translation Body centre of gravity clearly behind the binding
2e	Internal rotation in hyperextension or extension Upper body rotates in flexion
3b	Internal rotation in flexion
3c	Internal rotation + varus Ski tip turns inwards Body centre of gravity clearly in front of the binding
3d	Internal rotation + varus in flexion Body centre of gravity clearly in front of the binding
<b>MOVING DIRECTION BACKWARD</b>	
3e	Internal rotation + valgus in flexion (hip-below-knee) "Phantom Feet" Body centre of gravity clearly behind the binding
3f	Internal rotation + valgus + anterior-directed translation Body centre of gravity clearly behind the binding
4a	Hyperextension or extension
4b	Hyperextension + internal rotation + varus

Given the increased risk of knee injury in female skiers, females should receive particular attention with an equipment intervention (69, 83, 124). Cognitive awareness training to prevent serious knee sprains should also be considered

(329). The knee friendly skiing program developed by the Vermont Safety Research group to prevent ACL injuries encourages skiers to: keep knees flexed in backward falls, not fight to stay upright, and stay down until the slide has stopped rather than trying to recover (329). The Vermont education intervention was found to be effective in reducing ACL injury in ski area staff. NZ ski area staff that use their skis need annual checks on the integrity of the ski-boot sole and the ski binding. Checks of staff ski-binding-boot systems pre-season and repeats of these checks using torque testing during the season are common practice in North America, parts of Canada and Europe. Falls technique education, in particular ACL awareness (329) should also be included in ski area pre-season staff training. The Vermont ACL awareness guide to knee friendly skiing has not been used in a public education programme; checks should be made of this educational resource to determine whether this programme could be rolled out to a larger audience.

#### Terrain

Heads of Safety Services and senior ski patrollers surveyed online during the development of this strategy advocated for clearer descriptions of type/grade of terrain and education to make terrain choices that are a better match for ability. Reduction of the permissible speed on congested runs and in slow zones was promoted along with building wider trails in high-use zones.

#### Measuring patient status

For ski patrollers and mountain clinic staff the 2012 consensus statement on concussion in sport importantly standardised the definition of concussion (116). Using the standard concussion definition and moving beyond the present status codes would reduce subjectivity and provide greater description for evaluation of a helmet intervention. The Glasgow Coma Scale (GCS) is the neurological assessment tool used in the observations section of the SAANZ incident reporting form (235) but presently these observations are not recorded on the NID-S. It is recommended that the GCS score be used by ski patrollers in all head injury assessments; the GCS score is used by St John at all levels and as such should not present any difficulty. The coding for the NID-S will need to be updated to accommodate this change.

### Cultural change

All people invested in this strategy can multiply the reach of the strategy and make positive contributions to the evolving safety culture on the slopes. This ground-up endeavour will require injury prevention champions. Induction packages at ski areas should include education on active versus passive injury prevention. Industry staff should be aware of the season's injury prevention implementation plans, the progress being made in achieving the goals of this strategy and encouraged to make contributions both small and large. Ski area staff should also apply the injury prevention measures outlined in this strategy to ensure personal safety when skiing or snowboarding whilst at work or play.

#### **7.4.11 Evaluation**

This strategy has not outlined a snow sports injury prevention research programme per se, but has identified that there are many questions to answer, that research opportunities exist, and that robust evaluation is essential.

Speed was not a risk factor that was assessed in the 2010 – 2014 NID-S injury trend study; it is certainly worth quantifying actual speeds and worthy instituting interventions to stop the faster you go, the harder you fall phenomenon. Evaluating cultural change is more subjective than monitoring speed. Determining the retention of the new snow safety rules will provide some insight to the cultural shift over the next 5 years, as will quality assurance checks of education programs that are developed as a part of this strategy.

## Recommendations

- I. Undertake monthly independent analysis of the NID-S during the winter season.
- II. Utilise SAS code that has been written and tested.
- III. Calculate injuries per 1000 skier/boarder day (need monthly participation numbers).
- IV. Calculate domestic versus international injured per 1000 skier/boarder day (need separate resident and overseas participant numbers).
- V. Make formal arrangements with ACC for regular supply of raw snow sports injury data (new injuries, not the tail of old injury claims).
- VI. Analyse ACC snow sports claimant data in tandem with the NID-S.
- VII. Undertake annual counts of skiers and snowboarders wearing helmets versus bare heads.
- VIII. Add the first Glasgow Coma Score (GSC) score from observations in the SAANZ Incident Reporting Form medical notes into the NID-S dataset at the bottom of the form.
- IX. Continue to closely analyse the influence of the snow-pack on the incidence of injuries.
- X. Ensure interventions that target specific types of injuries are evaluated by the appropriate research method(s) and sample size.

It is also recommended that the SAANZ Injury Prevention Steering Group take over the role of the NZ Mountain Safety Research Committee to ensure that:

- The operational impact and mountain context has been adequately considered
- Access agreements are in place
- Written support is provided for research ethics and external funding applications.
- Reduce the risk of duplication of snow sports research.
- Make sure that industry benefits by requiring researchers with access agreements to report the findings.

Lastly, SAANZ would benefit from becoming members of the International Society for Skiing Safety, Fédération Internationale des Patrouilles de Ski, and ISO and/or the ASTM snow sport standards as affiliates. Membership would ensure that

new research and standards are disseminated; practice is informed; intervention design is enhanced; and changes in policy decisions are supported. The New Zealand snow sports industry will continue to head in the right direction by staying connected with the international community that advocates for informed change and contributing research that advances injury prevention in skiing and snowboarding.

#### 7.4.12 Implementation plans (2015 – 2020)

2015		
Focus Areas	Strategies	Actions
People-related risk		
Rules	Strengthen the Snow Users Responsibility Code	Rewrite and rename the code for roll out in 2016
Education	Build resources	ACC to film Snow Sports NZ athletes for 2016 campaign
Physical conditioning	Deliver key messages on food and fluid	ACC to design SportSmart principles mountain ad campaign
Build the baseline > gather the following data:		
Ski-bindings	April - June 2015: torque-test private skiers' ski-binding-boot systems to determine equipment-related risk of knee or lower leg injury. Establish how skier self-release manoeuvres compare with machine torque testing in determining ski-binding safety. Further inform industry decisions on torque-testing activity	
Preparation	July 2015: trial of an Auckland-based snow sports specific strength and conditioning programme	
Protective equipment	August 2015: determine number of bare-heads versus number wearing helmets (as per standardised method) Undertake stock-take at all ski areas of number of rental helmets and rental wrist protectors (include detail on length/design)	
Infrastructure	August – September 2015: explore management perspectives on potential barriers to the uptake of injury prevention measures October 2015: trial smart phone ski patrol incident software application to create easy download data to the NID-S	

2016		
Focus Areas	Strategies	Actions
People-related 2016		
Rules	Promote up-take of the new Snow Safety Code	Reduce poor decisions about terrain, snow conditions and sharing the slope Engage all people invested in the strategy to advance the safety culture Start the snow safety message off the hill and continually reinforce the benefits of living the code. Involve all ski area staff in in-person spread the code initiatives. Use multi-media channels relevant to the audience so that the new code is common language
Education	Expand the education brief of Snow Sports NZ	Employ a FUNdamentals' manager and an injury prevention resource developer for a 5-year term (2 FTE). Ensure that the new appointees have reporting lines and a collaborative brief to work with SAANZ general managers throughout NZ, the SAANZ Heads of Safety Services (HODs) working group, and the SAANZ Injury Prevention (IP) Steering Group. Synchronise meeting times each year of the strategy
	Provide on-the-spot quick education interventions for skiers and snowboarders that are out of control	Expand the working brief/expertise of courtesy patrol/ slope safety staff and offer short interventional education to any skier or snowboarder that is not in control

		Have ski school managers cost out a roving sponsored free instruction model for potential implementation in 2017
		Undertake an on-field review of fall techniques that may prevent injury
	Promote on-snow skill development to decrease the risk of being injured because of being untrained or due to skill lost after limited days on the snow.	Help skiers and snowboarders of all ages and capability to avoid collisions and falls by steering where they want to go, remaining in control whatever the snow condition, stopping safely and stopping quickly.
		Promote lessons
		Scope out sponsorship to incentivise participation in a 1, 2, paid 3 <sup>rd</sup> lesson free package. If a sponsor is found, role out new lesson packages
	Enhance on-snow good attitude that fosters respect on the mountain.	Reshape the attitudes of all age groups with injury prevention champions (high profile skiers and riders) promoting good decision-making
		Develop a programme that builds the snow safety culture Teach skiers and snowboarders about sharing space, respecting others and helping those in difficulty on-the-hill
		Target the young with in-school programmes so that safety is implicit in their actions going forward
	Expand snow sports instructors' understanding of injury prevention education.	Seek permission from the bfu to translate the Swiss instructors' weather-proof handbook: Snow-Safety Kartenset

		Unterrichtskarten für die Sicherheit beim Skifahren und Snowboardern. Determine what New Zealand modifications are needed and modify. Issue the SAANZ/NZSIA handbook to all instructors and provide a professional online update on injury prevention
Physical conditioning	Snow Readiness – promote physical and mental preparedness for the slopes	Encourage snow sport specific physical fitness before the season or winter holiday to reduce the likelihood of injury. Leverage off ski area client databases with get ready messaging
		Provide links to the most current international snow sports physical conditioning apps that have been reviewed and endorsed by SAANZ
		Promote: recreation at altitude requires aerobic fitness; being more agile, flexible, strong and conditioned will help create a ready mind-set for skiing and snowboarding; and strength and conditioning can reduce the incidence of back strain
		Advocate that NZ fitness instructors provide snow sports specific flexibility, strength and conditioning programmes that build core strength, increase dynamic movement with balance movement patterns that mimic skiing or snowboarding, and promote activities that increase physical resilience

	Alignment- promote professional checks of alignment when having boots fitted and whilst skiing or snowboarding	Assess alignment of female skiers and skiers returning to skiing after knee or lower leg injury. Link this at risk group to tailored education on the slopes
Specific injuries	Target specific injury types	Target reduction of knee injuries and lower leg fractures in skiers; wrist fractures in snowboarders; head injury, back strain and shoulder dislocation in both snow sports
Equipment-related 2016		
Ski-bindings	Promote torque-testing	Trial an on-hill torque-testing service at one or more ski areas
	Promote safe ski-equipment storage in the off-season	Wax bases and wind down the release settings (DIN) in the toe-piece and heel to zero in the off-season. Promote ski technician set-up equipment for current weight and skiing type each season
General injury	Advance rental-shop best practices	Adopt ISO standards 11088: 2006 (E) and 13993: 2001(E)
		Develop a SAANZ large format easy read release setting calculation chart
		Develop a national skier type poster and selection chart to improve calculation of correct release settings (DIN)
		Lower the release setting for at risk skiers based on AFNOR FD S 52-748

Environment-related 2016		
Sharing the slope	Reduce evasive acts and collisions	Take all opportunities to promote skiing and snowboarding in control
Terrain	Promote terrain choices matched to ability	Help skiers and snowboarders to make terrain choices that are a better match for ability by providing clear descriptions of the type and grade of terrain on signage and ski area maps
Injury Hotspots	Increase injury surveillance capacity	Create an open environment that allows sharing of NID-S data and GPS co-ordinate solutions that are operating at some ski areas. Rollout the Injury Hotspot App to all ski areas. Commence national GPS mapping project that includes green, black, blue grading detail (see, Appendix XI)
Terrain-park	Start small and work-up	Develop SAANZ terrain-park guidelines. Seek permission to translate bfu-Fachdokcumentation 2.081 Berartungsstelle fur Unfallverhutung and include all relevant material in these guidelines
Develop / roll-out a three pronged smart communication programme that connects with snow sports participants via the use of high profile NZ skiers and snowboarders with communication of integrated messages related to reduction of people-related, equipment-related and environment-related risks		
Determine the effect of the strategy actions by independent evaluation		

2017		
Focus Areas	Strategies	Actions
People-related 2017		
Rules	Increase up-take of the new Snow Safety Code	Ensure the Snow Safety Code is integrated into all IP interventions
Specific injuries	Target specific injury types	Consider findings of 2016 fall technique review. Continue to develop interventions. Engage researchers to ensure that targeted interventions have the appropriate measures to determine success.
Education	Increase up-take of education	Continue to enhance the reach of FUNdamentals and develop targeted education packages (in-school, terrain-based, female skiers, freestyle, post injury return to skiing and riding). Support school teachers' capacity to multiply the injury prevention message in schools. Roll-out the roving sponsored instructor model
	Increase public understanding of snow sports injury prevention	Develop a full media campaign
	Increase staff understanding of snow sports injury prevention	Develop workshop material for staff inductions. Provide an online resource of current snow sports research on the SAANZ website. Acknowledge injury champions in the workforce

Physical conditioning	Snow sport specific pre-season and in-season conditioning	Snow sport specific interventions continue
	Return to skiing after knee injury	Develop and roll-out a tailored programme that work on limiting knee inward collapse (valgus), buttock (glute medius) strengthening, hip exercises using a band and ankle dorsiflexion drills
Equipment-related 2017		
Helmets	Targeted reduction interventions	No-bare heads
Wrist-guards	Targeted reduction interventions	Wear an ISO recommended wrist guard if less than 30 days on the snowboard
Equipment	Targeted reduction interventions	Test and tune campaign (particularly target females on private skis)
Maintenance	Reduce risk of skiers and snowboarders unable to manoeuvre and glide	Reduce the friction by regularly waxing bases with wax suited to the snow conditions campaign
Gear-selection	Provide equipment advice	Increase awareness that shorter ski lengths reduce the lever arm forces involved in knee injury Encourage participation of NZSIF retailers in strategy initiatives
Eye protection	Partner with an eye company to improve visual acuity in different conditions	Protect the eye campaign Promote visual acuity tests Increase use of over the glasses (OTG) goggles

Environment-related 2017		
Mountain weather	Listen or read the mountain forecast and check the ski area websites before you head to the slopes	Be prepared campaign
Roll-out the three pronged smart communication programme that connects with snow sports participants via the use of high profile NZ skiers and snowboarders with communication of integrated messages related to reduction of people-related, equipment-related, and environment-related risks		
Determine the effect of the strategy actions by independent evaluation		

2018		
Focus Areas	Strategies	Actions / Indicators of Success
<b>People-related 2018</b>		
Rules	Strong simple rules reinforced by all	Ensure the Snow Safety Code is integrated into all IP interventions
Specific injuries	Target specific injury types	Ensure that targeted interventions continue to have the appropriate support to be effective
Education	Education on getting the best out of the skiing and snowboarding experience, improve skills and stay injury-free	Ensure that the FUNdamentals and targeted education packages continue to have the appropriate support to be effective. Undertake regular evaluation
Physical conditioning	Snow sport specific pre-season and in-season conditioning	Continue to encourage provision of snow sport specific programs
	Return to skiing after knee injury	
<b>Equipment-related 2018</b>		
Helmets	Targeted reduction intervention	Don't lose your capacity to think and dream big – wear a helmet!
Wrist-guards	Targeted reduction intervention	Riders with less than 30 days on a snowboard should wear an ISO approved wrist-guard to reduce the chance of a wrist fracture
Equipment	Targeted reduction intervention	Test and tune campaign (particularly target female skiers and those with previous knee injuries)

Maintenance	Reduce risk of being unable to cope with hard snow or ice	Sharpen your edges campaign
Gear-selection	Provide equipment advice	Chose a snowboard that can do the moves
Environment-related 2018		
Snow-pack	Provide snow-pack advice	Reduce the friction wax your bases campaign
Integrated messages related to reduction of people-related, equipment-related, and environment-related risks		
Assess the up-take of the three pronged smart communication programme		
Determine the effect of the strategy actions by independent evaluation		

2019		
Focus Areas	Strategies	Actions / Indicators of Success
People-related 2019		
Rules	Strong simple rules reinforced by all	Ensure the Snow Safety Code is integrated into all IP interventions
Specific injuries	Target specific injury types	Education and promotion of changes in behaviour for the seven target injury areas identified in the 2016 implementation plan
Education	Education on getting the best out of the skiing and snowboarding experience, improve skills and stay injury-free	Increase participation in FUNdamentals and targeted group education packages
Physical conditioning	Snow sport specific pre-season and in-season conditioning	Snow sport specific interventions continue
Equipment-related 2019		
Helmets	Targeted reduction intervention	Even with a helmet avoid hard knocks to the head, keep speeds in-check and stay in control
Wrist-guards	Targeted reduction intervention	Take a lesson and learn to limit the risk of wrist fracture Wear an ISO recommended wrist guard if less than 30 days on the snowboard
Equipment	Targeted reduction intervention	Test and tune campaign Make sure ski boot soles are not worn so that the boot is a safe fit with the ski-binding

Environment-related 2019		
The Cold	Raise awareness of the negative impact cold can have on decision-making capacities	Seek shelter and layer up the clothes to prevent hypothermia. Provide advice on signs of frost-nip
Mountain Conditions	Raise awareness of harsh effects of sun, reflection, wind and snow-crystals	Skin protection campaign
Refresh the three pronged message on reduction of people-related, equipment-related, and environment-related risks		
Determine the effect of the strategy actions by independent evaluation		

2020		
Focus Areas	Strategies	Actions & Indicators of Success
<b>People-related 2020</b>		
Rules	Strong simple rules reinforced by all	Evaluate capacity to recall the Snow Safety Code
Specific injuries	Target specific injury types	Analyse incident data over 5 years to determine reduction
Education	Education on getting the best out of the skiing and snowboarding experience, improve skills and stay injury-free	Undertake quality surveys on education packages
Physical conditioning	Snow sport specific pre-season and in-season conditioning	Promote updates of snow sport specific flexibility, strength and conditioning programmes by dissemination of new information
<b>Equipment-related 2020</b>		
Helmets	Targeted reduction intervention	Evaluate no-bare heads campaign by determining whether increased number wearing helmets have been associated with a decline in head injuries in skiing and snowboarding.
Wrist-guards	Targeted reduction intervention	Evaluate numbers and ability levels of those wearing wrist-guards
Equipment	Targeted reduction intervention	Determine improvement in set-up and maintenance with torque-testing by sampling rental and private ski-binding-boot systems

Gear-selection	Provide equipment advice	Update equipment advice in collaboration with manufacturers
Eye protection	Provide eyewear and visual acuity advice	Update eyewear advice in collaboration with manufacturers
<b>Environment-related 2020</b>		
Mountains	Enhance respect and safe behaviours in the mountain	Combine environmental messages from 2016 – 2020
Design	Continue to develop infrastructure	Utilise injury hotspot mapping to measure effect of improved trail-and terrain-park design
<b>Refresh the people-related, equipment-related, and environment-related risk smart communication programme</b>		
Write the NZ snows sports injury prevention strategy for the next five years		

### 7.4.13 Strategy summary

The *New Zealand Snow Sports Injury Prevention Strategy (2015 – 2020)* - a snow sports initiative has been developed from the ground-up in an inclusive process. Development has been based on expert industry input, external consultation, analysis of the magnitude of the problem using NID-S data over five winter seasons (2010 – 2014), and an extensive evaluation of current research on injury causation, injury prevention models, and possible solutions. This blueprint has a good mix of mountain pragmatism and snow sports injury prevention science. The effect-orientated prevention cycle and TRIPP framework have been fully utilised in establishing the injury prevention goals for snow sports for the next five years:

- Reduce the injury rate by 10% over the next 5 years.
- Increase enjoyable injury-free recreation at New Zealand ski areas.
- Collaborate to increase effectiveness and ensure the sustainability of this strategy.
- Inform decision-making with best-practice evidence and evaluation.
- Develop and implement appropriate injury prevention interventions.

The young skier in Figure 7.7 has a balanced stance on his skis, is well protected with a helmet, is wearing goggles to improve visibility, has up-to-date recently serviced equipment, is wearing clothes that are visible to others on the slope, and looks clearly focused on injury-free fun. The snow sports injury prevention culture needs to be grown by investing in applied snow safety knowledge across the lifespan, increasing all skiers and snowboarders capability to stay in control at all times, and enhancing respect for others sharing the slope. The call for continued injury prevention action in snow sports has been made.



Figure 7.7: In pursuit of injury-free fun

### **7.5. The new snow safety code**

The implementation plan for 2015 was enacted in tandem with strategy development. This action ensured momentum was not lost, and that the New Zealand Snow Safety Code launch occurred prior to the 2016 winter season (see Figure 7.8). The new code utilised text from Survey II favoured by respondents (see Table 7.4). The use of three key take out messages with subtitles informs skiers and snowboarders on the actions required. Alignment with the Outdoor Safety Code and the Water Safety Code on “know your limits” reinforces the message across three codes that all people recreating in the outdoors need to make informed choices in keeping with ability (221). The inclusion of promotion of skier boarder lessons shifts the code from a list of “do not’s” to solutions. Use of the “find your space” reduces the complexity of slope rules used in the FIS code of conduct and aims to improve situational awareness (see, Appendix IX). Protection gains a wider brief than the previous Snow Users’ Responsibility Code (see, Appendix IX) that only had obeying signage. The inclusion of “wear a helmet” and “tired, take a rest” open platforms for further education. Protection did not extend to equipment testing and maintenance or wearing wrist protection when learning to snowboard. These important injury prevention messages will require another medium. The snow safety code launched with funding from ACC is a real world outcome, the full reach of which is yet to be determined.

# NEW ZEALAND SNOW SAFETY CODE

## KNOW YOUR LIMITS

- > Ride to your ability, control your speed
- > Be aware of the conditions
- > Take a lesson

## FIND YOUR SPACE

- > Stop where you can be seen
- > Give others room
- > Look ahead

## PROTECT YOURSELF

- > Obey all signs and closures
- > Tired, take a rest
- > Wear a helmet

Logo here

New Zealand Government

ACC SportSmart

Figure 7.8: The developed code

## **7.6 Declaration**

From 1984 to 2001, the primary researcher was a ski patroller for Ruapehu Alpine Lifts at Whakapapa ski area, Mount Ruapehu, New Zealand. There were no conflicts of interest from previous work or undue influence from any one party. The researcher received no external funding. University research funds assisted with strategy publication costs.

## **7.7 Limitations**

Conference delegate responses to code development at the 2015 SAANZ conference (Cardrona Ski Area, Wanaka) highlighted the complexity of gathering all viewpoints. The decision by SAANZ to drive researcher industry engagement in strategy development through the SAANZ Head of Safety Services Group may represent a limitation. Not all people with an interest in safety service decision making at New Zealand ski areas may have received an invitation for Survey I. Survey II attempted to address this limitation.

The PICOS protocol reduced the potential for missing data in the review of literature. However, resourcing constraint existed with only one reviewer. Where possible two or more independent researchers should review titles, abstracts, conduct full text reviews for relevance and resolve any disagreement with discussion before inclusion. Feedback from my two supervisors during the strategy development sort to address the single reviewer limitation.

## CHAPTER 8 – PRACTICAL APPLICATIONS AND FUTURE RESEARCH

### 8.1. Introduction

The aim of the PHD thesis was to answer the overarching question “What strategies are needed to ameliorate alpine skiing and snowboarding injuries in New Zealand?” The injury prevention model “Translating Research in Injury Prevention Practice” (TRIPP) applied in this thesis ensured research efforts were purposeful and the end-goal remained in clear focus (15). Importantly, working through all six stages of the TRIPP framework translated thesis findings into practical outcomes. Other injury prevention models included in Chapter 2 and Chapter 7 added to this holistic undertaking, in particular the effect-orientated injury prevention cycle (46). The evidence presented in this thesis provides original research observations and helps recalibrate injury prevention efforts in snow sports in New Zealand. Stakeholders identified in Chapter 7 will need to continue to accelerate and champion this change.

### 8.2. Six stages

Injury Surveillance (TRIPP Stage 1) illuminated both the size and nature of the injury problem in snow sports in New Zealand. Comparison of the Accident Compensation Commission (ACC) and National Incident Database (NID) identified a bypass effect, a novel finding (413). Two-thirds of injured skiers and snowboarders presented to health practitioners off the mountain rather than seeking care at ski areas. Analysis of ACC claimant data established the true magnitude of the snow sports Injury problem (8.8 per 1000 skier/boarder days). Undertaking both ACC-NID comparison and a longitudinal study over five winters provided a more comprehensive picture. Sprains accounted for the biggest difference in injury rate between the ACC and the NID (5.3 and 1.3 respectively), commonly involving the knee. Knee injuries were the most common injury overall (36%). Over two thirds of knee injuries occurred in skiers when compared with snowboarders and others, tubing or hiking (76%, 21%, and 3% respectively).

Causation (TRIPP Stage 2) examined in the NID data found falls accounted for 74.3% of incidents (414). Effects of skier type (see, Appendix VIII), snow conditions and visibility conditions examined for the first time In New Zealand snow sports using

a hazards ratio approach. Hazard ratios for knee injury increased with non-release in hard snow for advanced skiers when compared to soft snow (2.2, CI 99%, 1.7 – 2.7 vs. 1.5, 1.2- 1.7). Raising concern that tighter binding release settings used by skier type III advanced skiers were increasing odds of injury. When visibility was good, and the snow soft, intermediate Type II skiers had a very likely increase of knee injury (hazard ratio 1.27, CI 99% 1.16 – 1.39). International standards for recommended release values do not factor in the wide range of skiing style attributed to type II or changes in snow conditions. Soft snow may slow the skier and increase the torque in a twisting fall changing the release requirements. Further investigation needs to determine adjustment recommendations for different skiing styles and snow conditions.

Poor visibility where full cloud cover led to flat light or white out conditions with snow falling, mist or rain and soft snow conditions most likely increased the incidence of knee injury (hazard ratio 1.63, 99% CI 1.38 – 1.89). Poor visibility potentially delays reaction time (163). Skiers who normally require prescription glasses and are not using corrective sunglasses or over the glasses (OTG) goggles when skiing in poor visibility may be at even greater risk of injury in such conditions. There was no literature or data on visual restrictions and the contribution of poor visual acuity to falls in skiers and snowboarders in southern hemisphere alpine conditions, a gap worthy of exploration. Strategy actions plans include promotion of visual acuity tests and increased use of OTG goggles. The effectiveness of an enhanced vision intervention needs to be evaluated.

Lower leg injuries for advanced skiers most likely increased in good visibility when the snow was soft versus hard (hazard ratio 2.06, CI 99% 1.55 – 2.7) another indication that this group of skiers release settings are too tight. In poor visibility, probability that advanced skiers injured the lower leg in soft snow versus hard snow was a likely increase (hazard ratio 1.63, CI 99% 0.94 – 2.71) raising further investigations of adjustment of release settings in different snow conditions. Intermediate skiers had a very likely increase in lower leg injury in good visibility (hazard ratio 1.34, CI 99% 1.12 – 1.60); however, in poor visibility and soft snow the results were unclear (hazard ratio 1.02, CI 99% 0.73 – 1.40). The NID release results add further weight to the need for vigilance during ski-binding set-up.

Subsequent examination of standards of practice of ski-binding set-up across New Zealand identified that only 10% of ski-technicians applied international standards and torque-tested ski-binding-boot systems (S-B-B). The common industry practice of discarding rental equipment after four years offered no surety that equipment was safe. Establishing an age effect using torque testing had not been examined in previous literature. We observed that class II deviations were 48% for S-B-B with two seasons of use. Of the rental fleet 3% with two seasons of use and 5% of the rental fleet with three seasons of use had Class III deviations meaning that these skis needed removing from service.

Potential solutions (TRIPP Stage 3) were to implement ISO standards; however, no commercial ski areas had torque testing machines or wrenches (90, 152). Testing time per set of skis was determined to be 10 minutes per set. Pre-season testing large rental fleets and sampling during the season thought labour intensive. Some SAANZ members viewed the additional labour and plant costs prohibitive. A potential alternative solution was that skiers undertake daily ski-binding safety checks with a self-release manoeuvre. However, the self-release manoeuvre had limited empirical testing to support an injury prevention campaign. Lack of evidence on the self-release manoeuvre provided the focus for the next experimental study of this thesis.

Assessment of the proposed self-release and self-adjustment intervention in ideal controlled settings (TRIPP stage 4) of the snow dome was another original aspect of this thesis. Skiers with more advanced skiing styles (Type II and Type III) were more likely to have S-B-B systems over the recommended release value than Type I skiers. Overly tight bindings could increase risk of injury as evidenced in chapter 6. Only 28% of participants could release at ISO recommended release torques, all others required lower release settings. Premature release on low settings could also increase injury risk. The self-release manoeuvre with or without self-adjustment did not replace the requirement for torque testing in determining ski-binding safety, further proof that New Zealand skiers would benefit from torque-testing services. Educating skiers on release settings also is required so that ski technicians receive accurate information on skiing style, weight and height before determining an individual's release setting. Finally, the descriptive grading system of ski boot wear developed for the study is potentially suited to inclusion in equipment standards and use by other researchers in ski-binding studies.

TRIPP Stage 5, description of the intervention context followed. This stage was both a sequential step and an essential thread through all stages of the doctoral journey (227). Time spent in the mountains in all weathers with a broad cross section of people revealed the operational complexities of attenuating injury at ski areas. Practical insights, review of the literature, survey and focus group data informed reduction strategies. Adapting the risk triangle used in outdoor education and recreation to snow sports was another original aspect of this thesis (12). Strategic action plans addressed the three aspects of risk identified in the triangle, people-related, equipment-related and environment-related risk. Repeats of the PDCA improvement cycle (415): plan, do, check and act complimented research action and solidified the communication bridge. Commitment to the community remained to the fore. Ultimately, what we do in research is with people and for people.

Implementation (TRIPP stage 6) pragmatically, work could not wait for a finished thesis of evidence-based solutions (416). In 2015, everyone that participated in the strategy development by way of survey or focus group had work to do, informed by the draft action plan. Chapter 6 resulted in a published strategy, a new snow safety code and evidence-based action plans adopted by Ski Areas Association New Zealand (SAANZ). Fourteen safety services department heads throughout New Zealand and the chair of the SAANZ Heads of Safety Services group are to enact the strategy in collaboration with ski patrollers and operations staff over five years. Investment by external stakeholders identified in Chapter 7 will also be required. ACC involvement in future snow sports injury reduction efforts will require continued dialogue and commitment by both parties. The new safety code potentially of use in other alpine countries, and possibly a replacement for the 1964 Federation Internationale de Ski (FIS) skier's code of conduct (219, 220).

Application of the Translating Research into Practice model (15) closed the research practice gaps that existed in New Zealand alpine skiing and snowboarding research. The TRIPP framework has proven an effective cohesive approach to injury prevention in snow sports. The TRIPP framework is suited to any research programme that seeks to find evidence-based solutions to mitigate trauma.

### 8.3. Future research

At the outset of the snow sports research programme those on the ground understood that research was essential but were challenged by the complexity and time-required for scientific evidence to answer problems (222). Future research needs to involve all or most major ski areas in New Zealand to ensure the sample size is sufficient and dissemination of results are timely. In 2015, seven ski areas accounted for 86% of the snow sports activity, this may change with commercial development at other resorts and/or snowfall patterns. New Zealand inclusion in multi-national studies would expedite our research endeavours. Snow sports research should focus on the major injury types, namely the knee, back, wrist, head and shoulder.

Effectiveness of initiatives outlined in the action plans of the strategy needs to be measured using ACC and NID data, not a single data set. Control data on the total snow sports population is also essential. Potentially skiers' place themselves at undue risk with higher release settings calculated by overstating ability. The accuracy of skier style selection to inform selection of ski-binding release settings warrants investigation. This recommendation for future research based on the evidence observed in chapter 4. Equipment testing of uninjured and injured skiers ski-binding-boot systems is required. With helmets promoted in the new snow safety plan bare head and helmet counts are needed annually at all ski areas. Counts will help determine the effectiveness of increased head protection. Pre and post implementation measurements will also be required when the wrist protection programmes start.

Risk factors for injury may be distant or proximal to the injury warranting continued efforts to increase understanding of all mechanisms at play (22, 32). Increasing understanding of risks, mechanisms and decision-making from a systems perspective of deaths at New Zealand ski areas would also be of benefit. Future analysis of any injury incidents should include the time of day ski areas opened and closed to determine the effect of time of day. Snow-pack data not solely surface conditions would also be of value given that injuries increased in soft snow, a surface condition that may include a variety of layers below the surface. The melt factor and bonding of manmade snow in comparison with other snow conditions needs investigating as this could increase or decrease playing surface risk. Wax also needs

testing in the maritime New Zealand snow surface conditions. Wax needs to be suited to the local conditions and reduce the friction associated with injurious moments. The new ski-binding rail system that has been adopted by some New Zealand ski area rental shops needs investigating as there was no data on the impact of this design (124). Does joining the toe-piece and heelpiece of the ski binding stiffen the waist of the ski and affect turning ability. Design changes to the ski-binding-boot system could increase (or decreasing) risk of falls and injury to the knee or lower leg.

Increased understanding is required on the demographic of skiers and snowboarders who delay seeking treatment, as early intervention may reduce severity and enhance recovery. Diminished neuromuscular control and loss of physical condition may be factors that limit return to snow sports (176, 204, 417). Research collaboration with physiotherapists treating snow sports injuries would be of value. Collaboration with ski instructors and coaches is also required to advance education initiatives. An effective functional exercise snow sport specific programs that focuses on preventing injury is also needed. ACL awareness education as promoted by the Vermont group could be of benefit to recreational skiers and New Zealand ski area staff (85). However, the Vermont ACL education program requires further testing.

Going forward a complex mix of stopping out-dated practices, continuing valid practices', modifying systems and interventions needed. Application of the snow safety rules, vigilance with equipment, and awareness of the ever-changing mountain environment constantly need engraining to ensure skiers and snowboarders make the right safety choices. Snow sports research disseminated to industry remains cardinal to all efforts to ameliorate snow sports injuries in New Zealand.

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## APPENDICES

### Appendix I: Ethics approval



A U T E C  
S E C R E T A R I A T

18 November 2014

John Cronin  
Faculty of Health and Environmental Sciences

Dear John

Re: Ethics Application: **14/146 ACC Client Cohort Study (ACC descriptor).**

Thank you for your request for approval of an amendment to your ethics application. I have approved the minor amendment to your ethics application allowing the addition of an anonymised survey and note the change of supervisor.

I remind you that as part of the ethics approval process, you are required to submit the following to the Auckland University of Technology Ethics Committee (AUTEC):

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/researchethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 19 May 2017;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/researchethics>. This report is to be submitted either when the approval expires on 19 May 2017 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at [ethics@aut.ac.nz](mailto:ethics@aut.ac.nz).

All the very best with your research,

A handwritten signature in black ink, appearing to read 'K O'Connor'.

Kate O'Connor  
Executive Secretary  
**Auckland University of Technology Ethics Committee**  
Cc: Brenda Costa-Scorse

4 May 2015

John Cronin  
Faculty of Health and Environmental Sciences

Dear John

Re: Ethics Application: **14/53 Ski-Binding Release**

Thank you for your request for approval of an amendment to your ethics application.

I have approved the minor amendment to your ethics application allowing changes to the inclusion criteria to include 14 years and over. The change of supervisor has also been noted.

I remind you that as part of the ethics approval process, you are required to submit the following to the Auckland University of Technology Ethics Committee (AUTEC):

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/researchethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 14 April 2017;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/researchethics>. This report is to be submitted either when the approval expires on 14 April 2017 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at [ethics@aut.ac.nz](mailto:ethics@aut.ac.nz).

All the very best with your research,



Kate O'Connor  
Executive Secretary  
**Auckland University of Technology Ethics Committee**

Cc: Brenda Costa-Scorse [brenda.costa-scorse@aut.ac.nz](mailto:brenda.costa-scorse@aut.ac.nz)



## Appendix III: Bare-head protocol

**Who: all commercial Ski Areas**

**When: August**

- on any blue sky week day
- and again on any blue sky Saturday
- 10 am to 11 am

**How:**

- have a person placed at the top of one of the major people moving lifts
- get them to count as people get off the lift

**What:**

- get a diligent person that is not easily distracted to perform the count
- use the tick-sheet (print off batches of 100)
- laminate the sheets for easy use and to ensure the paperwork doesn't get trashed if dropped on the snow
- use a permanent marker on the sheet
- record ski area/ lift name/ lift capacity/ date & day of week
- have the person counting tick in the skier or snowboarder column helmet or bare-head
- total each recording sheet
- also gather the total number of lift passes sold and season-pass holders for each day of the count

**+ Learners slope**

- at the same time of day at the learners area have a person take one wide-angle photo from the best vantage point
- to ensure that all subsequent photos are taken from the same spot record the GPS location and terrain feature where the photo was taken from

**Results:**

- Present your skier/boarder numbers, total counts for each day and provide duplicate photos of the learners area at the final SAANZ Safety Group meeting of the year.

## Appendix IV: Ski binding adjustment survey

 <p style="font-weight: bold; margin-top: 20px;">SKI BINDING ADJUSTMENT SURVEY 2009</p>	
<p><b>1. Present position</b> Which of the following best described your ski industry employment?</p> <p>Please tick <u>one</u> response that best applies to you.</p>	
<p>Full-time ski rental worker [ ] [ ]</p> <p>Part-time ski rental worker [ ] [ ]</p> <p>Full-time ski retail &amp; rental worker [ ] [ ]</p> <p>Part-time ski retail &amp; rental worker [ ] [ ]</p> <p>Only retail new skis [ ] [ ]</p> <p>Ski mechanic [ ] [ ]</p> <p>Manager ski rental operation [ ] [ ]</p> <p>General Manager or Owner with overall responsibility for standards of ski rental services [ ] [ ]</p>	
<p><b>2. Which of the following best describes your background in adjusting skis as a part of your employment?</b></p> <p>New this season [ ] [ ]</p> <p>1-3 seasons [ ] [ ]</p> <p>Over 3 seasons [ ] [ ]</p>	
<p><b>3. What orientation did you receive specific to adjusting ski bindings in 2009?</b></p> <p>No orientation [ ] [ ]</p> <p>Relyed on my own experience [ ] [ ]</p> <p>Informal demo from other staff [ ] [ ]</p> <p>In a workshop run by my employer [ ] [ ]</p> <p>In a workshop run by my employer with additional input from ski industry reps [ ] [ ]</p> <p>Completed NZQA unit standard education [ ] [ ]</p> <p>Overseas experience had recent training update [ ] [ ]</p> <p>Overseas experience had <u>no</u> recent training update [ ] [ ]</p>	
<p><b>4. Do you use a ski binding calibration testing device?</b></p> <p>Yes [ ] [ ]</p> <p>No [ ] [ ]</p> <p>If yes, what type:</p> <p>.....</p>	

<p><b>Adjusting Ski Bindings</b></p>	
<p><b>5. Do you use a ski binding retention table to determine the correct setting?</b></p> <p>Always [ ] [ ]</p> <p>Sometimes [ ] [ ]</p> <p>Never [ ] [ ]</p> <p><small>This table is often referred to as the DIN chart (DEUTSCHE INDUSTRIAL NORM)</small></p>	
<p><b>6. What type of ski binding retention table do you use?</b></p> <p>ISO 11088:2006 (skier weight, height, ability, boot sole) [ ] [ ]</p> <p>ASTM F939 (USA) [ ] [ ]</p> <p>Skier tibia width table (ISO / German) [ ] [ ]</p> <p>AFNOR FD S 52 – 748 (French) [ ] [ ]</p> <p>Manufacturer [ ] [ ]</p> <p>Specify the manufacturer &amp; and list the cross reference to a standard number</p> <p>.....</p>	
<p><b>7. Do ski binding adjustment practices change during rush hours?</b></p> <p>Never [ ] [ ]</p> <p>Sometimes [ ] [ ]</p> <p>Often [ ] [ ]</p>	
<p><b>8. Do clients accurately indicate their alpine skiing ability?</b></p> <p>Always [ ] [ ]</p> <p>Sometimes [ ] [ ]</p> <p>Never [ ] [ ]</p> <p><b>If sometimes, what do clients say about their alpine skiing ability?</b></p> <p>Understate [ ] [ ]</p> <p>Overstate [ ] [ ]</p> <p>Unsure- clients ask for a more detailed description of skier type to more accurately define their ability [ ] [ ]</p>	
<p><b>9. Do you factor in snow conditions when setting ski bindings?</b></p> <p>Yes [ ] [ ]</p> <p>No [ ] [ ]</p> <p>If yes, describe what snow conditions would prompt you to use a different binding retention setting than recommended on the table</p> <p>.....</p>	
<p><b>10. Do you factor in age when setting bindings?</b></p> <p>Yes [ ] [ ]</p> <p>Sometimes [ ] [ ]</p> <p>No [ ] [ ]</p>	
<p><b>11. Do you factor in fitness level when setting bindings?</b></p> <p>No [ ] [ ]</p> <p>Sometimes [ ] [ ]</p> <p>Yes [ ] [ ]</p>	

<b>12. Do you use lower settings?</b>		
For young people under 14 years	[ ]	[ ]
For females	[ ]	[ ]
For beginners of 7 days skiing or less	[ ]	[ ]
<b>13. Do you check the skier's weight?</b>		
Rely on what the skier states	[ ]	[ ]
Sometimes	[ ]	[ ]
Always	[ ]	[ ]
<b>14. Do you check the skier's height?</b>		
Rely on what the skier states	[ ]	[ ]
Sometimes	[ ]	[ ]
Always	[ ]	[ ]
<b>15. Do you check the sole of the ski boot for wear and tear?</b>		
Always	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]
<b>16. Do you measure the foot to ensure correct ski boot sole length?</b>		
Always	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]
<b>17. Do you check for boot binding compatibility?</b>		
Yes	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]
<b>18. Do you check the ski binding in the following movement pattern?</b>		
Twist only (toe piece)	[ ]	[ ]
Forward lean only (heel piece)	[ ]	[ ]
Twist & forward lean	[ ]	[ ]
<b>19. Do skis get returned for readjustment?</b>		
Infrequently	[ ]	[ ]
Frequently	[ ]	[ ]
If frequently, is there a common reason?		
.....		
<b>20. Do you adjust the binding setting up or down if asked by the customer?</b>		
Yes	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]
If sometimes do you have the customer sign the rental agreement confirming that they have requested to deviate from the recommended binding setting?		
Yes	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]

<b>21. Do you understand your role in injury prevention?</b>		
Yes	[ ]	[ ]
Partially, would like to know more	[ ]	[ ]
No	[ ]	[ ]
<b>22. When do you think there is increased risk of injury to the lower leg or knee?</b>		
Ski binding retention set too high	[ ]	[ ]
Ski binding retention setting set too low	[ ]	[ ]
<b>23. What do you think is the most common injury in alpine skiers?</b>		
Head	[ ]	[ ]
Shoulder	[ ]	[ ]
Wrist	[ ]	[ ]
Thumb	[ ]	[ ]
Knee	[ ]	[ ]
Lower Leg	[ ]	[ ]
Ankle	[ ]	[ ]
<b>24. What is the overall average injury rate for skiers in NZ?</b>		
4 per 100 (skier days)	[ ]	[ ]
4 per 500	[ ]	[ ]
4 per 1000	[ ]	[ ]
4 per 10,000	[ ]	[ ]
4 per 100,000	[ ]	[ ]
<b>25. Is injury prevention information supplied to the skier in your place of work?</b>		
Always	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]
If injury prevention material is supplied, define the type(s)		
Poster	[ ]	[ ]
Pamphlet	[ ]	[ ]
Video	[ ]	[ ]
Ski Rental Worker verbal instruction	[ ]	[ ]
Website	[ ]	[ ]
<b>26. What ski area or geographical region do you work in?</b>		
.....		
<p>Thank you for completing this questionnaire and participating in this important survey. Please place the completed questionnaire in the return envelope provided (no stamp required), and return by the 10<sup>th</sup> of September 2009.</p> <p>Brenda Costa-Scorse  Institute of Sport &amp; Recreation Research NZ  AUT University  Private 92006  Auckland 1142  +64 9 921 9999 Ext 7802</p>		

12. Do you use lower settings? For young people under 14 years	[ ]	[ ]
For females	[ ]	[ ]
For beginners of 7 days skiing or less	[ ]	[ ]
13. Do you check the skier's weight? Rely on what the skier states	[ ]	[ ]
Sometimes	[ ]	[ ]
Always	[ ]	[ ]
14. Do you check the skier's height? Rely on what the skier states	[ ]	[ ]
Sometimes	[ ]	[ ]
Always	[ ]	[ ]
15. Do you check the sole of the ski boot for wear and tear? Always	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]
16. Do you measure the foot to ensure correct ski boot sole length? Always	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]
17. Do you check for boot binding compatibility? Yes	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]
18. Do you check the ski binding in the following movement pattern? Twist only (toe piece)	[ ]	[ ]
Forward lean only (heel piece)	[ ]	[ ]
Twist & forward lean	[ ]	[ ]
19. Do skis get returned for readjustment? Infrequently	[ ]	[ ]
Frequently	[ ]	[ ]
If frequently, is there a common reason?  .....		
20. Do you adjust the binding setting up or down if asked by the customer? Yes	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]
If sometimes do you have the customer sign the rental agreement confirming that they have requested to deviate from the recommended binding setting?  Yes	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]

21. Do you understand your role in injury prevention? Yes	[ ]	[ ]
Partially, would like to know more	[ ]	[ ]
No	[ ]	[ ]
22. When do you think there is increased risk of injury to the lower leg or knee? Ski binding retention set too high	[ ]	[ ]
Ski binding retention setting set too low	[ ]	[ ]
23. What do you think is the most common injury in alpine skiers? Head	[ ]	[ ]
Shoulder	[ ]	[ ]
Wrist	[ ]	[ ]
Thumb	[ ]	[ ]
Knee	[ ]	[ ]
Lower Leg	[ ]	[ ]
Ankle	[ ]	[ ]
24. What is the overall average injury rate for skiers in NZ? 4 per 100 (skier days)	[ ]	[ ]
4 per 500	[ ]	[ ]
4 per 1000	[ ]	[ ]
4 per 10,000	[ ]	[ ]
4 per 100,000	[ ]	[ ]
25. Is injury prevention information supplied to the skier in your place of work? Always	[ ]	[ ]
Sometimes	[ ]	[ ]
Never	[ ]	[ ]
If injury prevention material is supplied, define the type(s) Poster	[ ]	[ ]
Pamphlet	[ ]	[ ]
Video	[ ]	[ ]
Ski Rental Worker verbal instruction	[ ]	[ ]
Website	[ ]	[ ]
26. What ski area or geographical region do you work in?  .....		
Thank you for completing this questionnaire and participating in this important survey. Please place the completed questionnaire in the return envelope provided (no stamp required), and return by the 10 <sup>th</sup> of September 2009. Brenda Costa-Scorse Institute of Sport & Recreation Research NZ AUT University Private 92006 Auckland 1142 +64 9 921 9999 Ext 7802		

## Appendix V: Standards of practice interview questions

1. Do you think that in general workers that adjust ski bindings understand their role in the prevention of injury?
2. Do you think that in general workers that adjust ski bindings understand the mechanics of injury to the lower leg and knee?
3. Do you think that in general workers that adjust ski bindings know what is required for safe functioning ski binding release?
4. Does your place of work have a ski binding adjustment policy?
5. Do you have an operations manual?
6. What input do you receive from commercial binding manufacturers?
7. What training is provided to workers that adjust ski bindings to ensure best practice standards are understood and being applied?
8. What advice is given to customers purchasing new bindings?
9. What is your place of work service and ongoing maintenance schedule for rental equipment?
10. When is rental equipment retired from rental service?
11. Do you have any suggestions for improvements in current service?
12. Do you have any suggestions for education packages for staff?
13. Do you have any suggestions for education packages for skiers?
14. Are there any other comments you wish to make in regards to this research?

## Appendix VI: Standards of practice interview results<sup>4</sup>

Unless indicated by n=\*, the comments are that of one individual.

Do you think that in general workers that adjust ski bindings understand their role in the prevention of injury?

96% answered yes

Huge variation, some do very well, some are boarding on criminal with little experience in a sport more dangerous than bungee.

### 1. Do you think that in general workers that adjust ski bindings understand the mechanics of injury to the knee?

Probably not / depends on experience	Yes
2 / 8	13

They understand the importance not the specifics

Not sure that the links are made to the nature of injuries

Yes, personal experience as I have had a knee injury

Probably not unless they have been to a physiotherapist with a knee injury

Depends what level

Experience is a big factor, it gives them a better insight, they realize their responsibilities (n= 8)

### 2 Do you think that in general workers that adjust ski bindings know what is required for safe functioning ski binding release?

Yes	No	Unsure	Depends on level / experience
17	12	2	2

- High turn-over impacts on understanding of requirements

<sup>4</sup> Results disseminated to SAANZ members in a technical report for ACC (207) that included ISO 13993: 2001 (E) purchased by ACC under limited reprint licence (1 October, 2008).

- Novice staff are an issue
- Returning staff have lived experience, they learn by osmosis
- Takes a season to orientate
- Staff focus is on getting out skiing or boarding
- With seasonal staff it is tricky to get the message across
- Position descriptions are presently being established with training plans and measurements of success
- There has been no closed safety management loop, accidents were recorded then filed, we now have a register listing things active until investigation and mitigation is completed
- Fairly good understanding of twist, forward pressure, and centre on the ski, I am pretty confident that staff understand the requirements
- Yes, we definitely all know what is required for safe functioning bindings but there are always the determined skiers who will increase the DIN setting themselves or make requests a higher setting. In these situations we record R for request on their hire form (n = 12)
- Customer sign off their requests
- Internationals generally know their DIN setting when hiring gear but this is less common with locals

**Does your place of work have a ski binding adjustment policy?**

Ski-field Rental	Yes	7
Artificial Slope Rental	Yes	1
Off field Rental Shop	Yes	1
Off field Rental Shop	In development	1
Off field Rental Shop	Yes, but not written down	6

- Yes we have a policy but I am not sure of the specifics
- No mechanical tester, I find this is a bit weird as even small shops in the States have calibration machines or torque wrenches which are a lever with 2 readings
- We use a computer system to work out the correct setting, this system only makes extra adjustments for over 50 years (n = 3)
- We use based our computer system on the Tyrolia DIN
- The Tyrolia calculator factors in tibia measurement, this is our surety that we have it right
- I don't ever use a ski binding release value table
- Our policy is to test all bindings by mechanical calibration at the beginning of the season, then a representative sample in mid-August. If a binding is out by 1.0 we decommission that ski if the binding setting is out by 0.49 we put a sticker on the ski so that difference is factored in when the skis are set for a client. We do not use a manual torque wrench as to ensure accuracy the same person needs to do all the skis, plus use the same motion all the time, potentially there are inaccuracies if there is a different person, and you need to be very

focused on what movement the arm is making when testing with these tools.

### 3 Do you have an operations manual?

Ski-field Rental	Yes	7
Artificial Slope Rental	Yes	1
Off field Rental Shop	Yes	1
Off field Rental Shop	In development	1
Off field Rental Shop	No	6

- Staff are not necessarily lateral at solving problems they just follow the system
- There are operational manuals in each department but these are not in a standardised format
- Yes we have a manual but I am not sure of the specific content
- We don't have an operations manual, you can have a manual but that does not mean people read it (n = 3)
- We use to get a lot of manufacturer manuals but we now often get new gear with no literature (n = 2)

### 4 What input do you receive from commercial binding manufacturers?

None	Some
14	9

- All respondents expressed a desire to have more product education from the manufacturers (n = 23)
- Manufactures appear to have given up on education input (n = 20)
- Possibly less education from manufacturers because some skis come pre-mounted bindings
- We have Salomon input as a part of the testing program but there is not enough education on gear (n = 3)
- They only come in when they want to sell us a new product
- When it was a lifestyle business reps were better, now it is more commercial
- The company may be moving to Head BYS (Black, Yellow, Silver) system which has 3 different sole lengths with clear markings for the boot. This system commits us to Head Skis but is simpler to work in large volume rental operations. The change in system will mean potentially retiring gear that has been in service for less than 3 years so this is a big undertaking (n = 5)
- One system of gear has limitations as peoples feet are suited to different brands

- Getting replacement spare parts is sometimes a hassle. Manufacturers apparently have higher import duty on spare parts but I am not sure if this is true. New Nordica boots come with an extra heel and toe soles, most other boot brands don't have replacement parts at time of purchase and one off items can be exorbitant. It would be good if manufacturers were required to provide a spare set of heel and toe pieces. Some new boot systems are fully moulded without replaceable soles. Apparently, Taranaki Rubber Company produces replacement soles for boots. AFD plates are easy to replace. Some binding brands have inbuilt anti friction roller devices rather than the AFD (n = 4)

**5 What training is provided to workers that adjust ski bindings to ensure best practice standards are understood and being applied?**

- I have downloaded the bosses extensive knowledge (n = 2)
- We coach on the job
- Role modelling
- Work through mock hire, and checking system scenarios
- Frequent checks from someone more senior
- Have a work climate that encourages staff to ask questions
- Have a boot fitting and ski tech background helps
- Completed courses overseas
- Completing the Snow & Rock (UK) comprehensive staff training package has been invaluable
- We target training proportional to what the persons role is
- All staff have general health & safety education (n = 2)
- First aid education helps with staff understanding of injury
- It would be good to include injury prevention education in staff training
- They are trained well; we have a training week (n = 10)
- We have 3 days pre-season where staff go over: boot fitting, maintenance of toe and heel pieces, junior and adult fitting, the ski binding release value table, and we cross over boot sizes to see their response
- Speed testing to ensure they do it fast plus get it right
- Staff are given the choice to do SFRITO unit standards 17 credits level 4 for technical workshop and 8 credits for level 3 rentals
- SFRITO industry training within the company is presently under review due to changes in the costing model by the ITO (n= 4)
- Our ski-field is no longer involved in SFRITO training but the unit standards did provide a good template for the way we think about staff training
- SFRITO initially was a gravy train. I take unit standard qualifications with a grain of salt. I don't trust the rigor as it is impossible not to pass. This is similar to a first aid course I was on recently where a person who was too big to do CPR to an effective standard passed the course
- The SFRITO unit standard is very general as it refers the student back to the manufactures guidelines so I am not sure what the point of this unit standard is
- Unit standards are a waste of time lots of excessive paper work for not much gain; ticking boxes with no real testing
- NZQA, I like the simple steps and a defined pathway, difficult though to get part-time staff to do all the work involved (n = 2)

- In Canada we use to do a Salomon course, overseas most courses for rental staff were 10 hours
- We have a big turnover of staff so we stay away from binding that are difficult to adjust
- We need to be all singing from the same hymn book with staff education. Expertise is in the industry not on the outside
- Pushing computer systems for binding adjustments is a no brainer
- Manual testing methods that present OOS injuries, this is important when we make purchase decisions where staff, thumb only adjustment check of the toe piece (n = 2)

**6 What advice is given to customers purchasing new bindings?**

- 19 interviewees were not involved in sales / 4 were involved in sales
- Occasionally give advice to people who have bought skis off the internet who have attempted to set up their own gear unsuccessfully (n = 2)
- Performance rentals often lead to people going out and buying
- With modern construction skis are like scalded cats that whip around taking skiers to their anatomical limits and their abilities, new gear choice opens the door for a mismatch to the customer

**7 What is your place of work service and ongoing maintenance schedule for rental equipment?**

- Constant vigilance, all gear is checked on return for damage and if screws are OK (n = 11)
- Not as good as it could be
- We tuned before school holidays as don't get a chance during this time to look at bases, edges, binding & cleaning
- Executive skis are tuned and waxed every time, as far as regular gear just when we spot something (n = 3)
- Bindings are removed from tracks, clean grit, re-grease but we have an enormous fleet
- Use marine grade grease in the past with bindings we used silicone sprays
- At the end of season we wind down the adjustments for storage
- Most binding manufacturers say to store skis with binding adjustment left in the middle range (n = 2)
- There is no specific tool to clean railings but the Robot tuning machine is great as high pressure water is used when the machine sharpens the edges which effectively cleans the binding; the quality of our tuning has improved ten-fold
- We have lots of spare parts like a toe piece not the heel so we often help customers if they break one binding

**8 When is equipment retired from rental service?**

- Most common range 3 – 4 years
- Cycle one third new every season
- 4 year old stock are kept as back up
- Days of user higher on an artificial slope average life of skis 2.5 years
- If there is rock damage gear is retired faster

- Changing gear is not just because of wear and tear, customers wanted the latest equipment
- We sell off our rental gear, with some going to club fields
- We don't sell off our rental gear as we don't want any associations with any future problems
- It is important that second hand ski sales do not pass on gear of poor standard to unsuspecting purchasers (n = 4)
- Gear is better manufactured than 10 years ago. In the eruptions on Ruapehu in 1995 – 96 we replaced all the bindings, and now with no rope toes, Cats not dropping oil and with snow making there is less dirt and debris that can get into the binding, this could still be an issue on some fields
- Smaller rental outlets and club fields will have more difficulty in turning over stock (n = 2)

## 9 Do you have any suggestions for improvements in current service?

- Ski Rental should be under a standards regulation, if you want to be a travel agent you have to have AFTA accreditation, industry should reward people who do it well
- Independent evaluation to see if a rental shop is safe or not safe
- National stance on which measures to use
- Skier Type suggest using conservative as a term rather than beginner, and intermediate or moderate is quite a leap, it would be good to agree on the descriptions and if there are three levels of skier or five levels (n = 2)
- Most rentals err on the side of caution and have recreational binding systems that only go to a DIN of 9.0. Performance bindings go up to 16.0
- Standardized binding setting charts that are easy to read because some people skim over the chart especially if they have complicated arrows going up and down
- Standardized questions about skiing ability; for example, do you ski aggressively or do you like "cruisey" skiing, when did you last ski, how many days do you ski on average? This provides more background to interpret skier type accurately (n = 2)
- Foot measurements mats like the Burton floor mat or slide measure foot plates (n = 3)
- Follow up, not just location of accident but analyse the cause (n = 4)
- When staff report back on health & safety actions, the trends of injuries are not included, I can see that this would be useful
- The hazard focus in health & safety is on the staff rather than customers this needs to be broadened
- Issues are assessed and we have a hazard atlas that charts areas for mitigation of risk but perhaps more could be done by adding in the patterns of injury information
- Need to have random on field checks on DIN settings (n = 2)
- Kiwi culture means ski adjustment standards are not taken seriously as we can't get sued, we need to get serious
- Customer service skill development, some people don't like being labelled a beginner but may have had on 7 days of skiing in the last 2 seasons so workers need to know how to question customers properly.

I think some people do not like saying they are a beginner because of their perception that that means they will get poor gear

- Increase in rental space, it is claustrophobic, design needs to allow for more / better flow of people
- Need to not feel so rushed (n = 3)
- Special groups establish weight, height and shoe size before arrival, we try to have school groups details on each child with marker pen or tag
- Other languages: French, German, Spanish, or Japanese staff help but we have had none this year. It would be good to have charts with questions in other languages. Although generally overseas visitors are not rank beginners
- Random shoppers focus on customer service, this could be focused on accuracy in ski & boot fitting
- Boot fitting should be included in all rental settings to ensure that boots are not too big and there are no crinkly socks (n = 2)
- Good documentation is important, particularly if increased DIN releases as occasionally we have had customers that report something going wrong and they are shopping for compensation such as a free ski pass for something we have not done or they plan to sting their insurers back home (n = 4)
- Rentals purchased on price rather than quality and safety is an issue especially in the back packer market
- Brake systems are needed for wide skis and snowboards
- Philosophy overseas is different with liability an issue for all businesses
- Positive in NZ that we have not gone down the law suit route but as an industry we need to be assuring customers that we are looking after their wellbeing. If we ensure good procedures and practices we are guaranteed
- Technology has changed but it blows me away that we are using wax scrapers in workshops that stress the wrist and thumb should be a scraper like a workshop planer
- Requirement to store rental documents for a certain period of time. We were challenged by a customer complaint months after his knee injury and fortunately found the documentation that we had taken into account he was over 50 and on the right DIN
- Don't ever hear back from ACC why things occur? It would be good to know more, if there is a pattern

#### **10 Do you have any suggestions for education packages for staff?**

- Statistics updates of injury patterns for rental staff (n = 4)
- Need to check DIN setting at the time of injury (n = 2)
- Need to specify the name of the hire centre on forms not just that skis are owned or rented, these businesses should be in the feedback loop (n = 2)
- Reinstating the requirement to measure the foot length (n = 2)
- Improve understanding of fitting children, we start them on 0 and move them up to 1 once they can get on a chairlift
- Guidance on what we should do in terms of accounting for physical conditioning and being overweight as they can pre-release and there bones aren't necessarily stronger

- When kids are over 60kg they are too heavy for junior gear but if they are 50 kg there is a greater chance the screws will pull
- We receive no specific education from ski patrollers, more education would be useful (n = 5)
- Workshops and help from reps (n = 17)
- A mechanics of injury video would be useful, importance of correct settings, consequences of not doing it right (n = 5)
- The Vermont Phantom Foot Video was an effective reminder when I worked in the States at the start of each season
- It used to be 40,000 per knee instruction so US employers were always keen to reduce the number of staff with knee injuries, it would be good to know the actual costs here
- Official material from ACC passed on through manuals

#### **11 Do you have any suggestions for education packages for skiers?**

- ACC need to move away from disseminating the safety message on paper, it is old technology. Traditional information methods no longer have the impact
- Posters need to arrive in a format we can use that is hard wearing like the advertising material from companies like Coca-Cola, framed or in Perspex
- Our ski-field emails 45,000 skiers a week with updates, injury prevention messages could be tagged to these communiqués
- It would be good to see ACC capitalize on the ski field web sites
- Flat screens would be a better medium than posters (n = 2)
- We would definitely use a DVD
- Check out Whistlers material
- A video game with a safety message would be great
- ACC appear to take a stock standard approach with sports injury prevention, recreational skiing is different from competitive team sports like Rugby. The rugby player wants to win so the stretch message and the conditioning messages probably get across with skiing they don't
- Provide safe binding adjustment information near screw drivers on the hill (attached to outdoor tables)
- Educational messages in chairlift cues
- Safety codes & specific safety messages on chairlift bars related to protecting knees
- ACC sponsored tow pads
- The timing of the education message is important, with the lift ticket perhaps but people don't read
- Skiers responsibility code has value but I think it is time that it is reviewed, has the message worn out, I still think it is very good though
- The car sticker day with ACC driving tips and scrapers was a great initiative this season
- What are the Ski Instructors Alliance presently doing to reduce injury?
- Teaching skiers learn how to fall and that are they should not try to get up when the ski is still moving
- Talking to beginners in the learn to ski packages, that is when they should be taught
- Learn to ski packages only involve the on-field ski rentals now this has cut out the incentive for us, we refer beginners to the Ski-field package

and then hope that they return as a customer after a few days once this package has expired as our hire is cheaper; it would be good to receive incentives from the Ski Areas for this support

- Half the people are beginners. We are so busy it is madness. We don't have time for explanations. It is just a factory throwing them out the door. We would need to get the message across in places outside rentals (n = 3)
- Rental outlets are often the first point of snow industry contact education has got to start here
- Material on the importance of cleaning boots, replacing heel and toe pieces, and replacing Anti Friction Devices to ensure functionality of the binding toe piece
- Buying cat tracks for walking in boots, a \$50 spend helps keep the sole in tact
- South Island unsealed roads are an issue if skis are on the roofs of vehicles, bindings get dirty, people need to be made aware that dust makes a binding stiff
- New binding designs have helped reduce the impact of dust and grit as there are less open working parts but it is still an issue with old gear (n = 2)
- List of binding models that are deemed unsafe so that when customers asked for these skis to be tuned we can provide supportive information to ensure the gear is binned (n = 2)
- Obsolete / vintage is the biggest issue in terms of accidents due to gear failure, we need a throw it out campaign (n = 3)
- Often people want to buy a new set of skis but move their old bindings, this should not be allowed what they can't see is the rusty worn spring mechanism. Calibration machines would help pick this up.
- Negligence of owners with equipment that has had its day is a real issue
- More people are renting, with some driven by the excessive luggage charges of the airlines, others by the fact you get up to date well serviced safe gear, this message needs to be pushed
- In the American Ski Magazines in the 90's the car tuning analogy was used similar advertising here would be good before the start of the season so that they have their gear checked and tuned
- Advertise the risk of skiing or boarding with I-pods, they cannot hear those around them, and I do wonder if it effects their balance and tunes them out to the risks
- Got to keep it brief, people don't like to think about injury, need to into account it is an adrenaline sport and some people don't want to listen, campaigns need to use the sports champions, characters that these guys can relate to
- I don't think urinals are the appropriate place for the skier code message
- Customers often don't understand why they need to divulge private information like weight, anything that helps them understand would be good

## 12 Are there any other comments you wish to make in regards to this research?

- Good to see it happening

- This is a good time to recap where we are at compared to international norms
- National campaigns, need to make informed decisions so this data will be great
- It would be good to know if knee injuries have changes since skis dropped in length
- Would like to know how many faulty bindings are picked up by calibration machines
- Worthwhile, interested to get some feedback as we want to get things as safe as possible
- Is modern skiing technique leading to the problem? The wider stance with rolling the ankle
- For the future: helmets do they reduce risk or are we just covering our butts; what do leashes do on snow boards- design snow board brakes; raise awareness of behaviour that is risky; lack of fitness to ski; determining trail safety measures as we effectively have the same issues as road design; countering the perception that snow boarders cause accidents; look at exhaustion in relation to injury; look at standards for the rental of snow blades restricting those of a certain height from hiring (n = 9 in total, but individual comments some of which were replicated)
- This research is better late than never, there is no point having people injured so anything that we can do to help prevent injury is a win-win for us
- We want to make some ones holiday not break it or reduce their mobility later in life.

## Appendix VII Consent and assent forms

### Ski-Binding Release Performance Testing Consent Form



Project title: Ski-Binding Release

Project Supervisor: Professor John Cronin

Researcher: Brenda Costa-Scorse

- I have read and understood the information provided about this research project in the Information Sheet dated 24 April 2015.
- I am in the age group 14 years and over.  
I have had an opportunity to ask questions and to have them answered.
- I understand that demographic data will be collected, physical measurements will be taken, the skis' will be torque-tested using a machine, and that I will undertake on-snow performance tests for self-release and self-adjustment.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If I withdraw, I understand that all relevant information will be destroyed.
- I agree to take part in this research.
- I am aware that a summary of the findings from this research will be posted on the Snowplanet website and in-print on Snowplanet's noticeboard.

Participant's signature: .....

Participant's name: .....

Date:

Approved by the Auckland University of Technology Ethics Committee on the  
17th March 2014 AUTEK Reference number 14/53

**Ski-Binding Release  
Performance Testing  
Parent/Guardian Assent Form**



Project title: Ski-binding Release Study  
Project Supervisor: Professor John Cronin  
Researcher: Brenda Costa-Scorse

- I have read and understood the information provided about this research project in the Information Sheet dated 24th April 2015.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw my child/children or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If my child /children withdraw, I understand that all relevant information from the ski-binding release study or parts thereof, will be destroyed.
- I agree to my child/children taking part in this research.
- I am aware that a summary of the findings from this study will be made available via the Snowplanet website.

Child/children's name/s:

.....

Parent/Guardian's signature: .....

Date:

Approved by the Auckland University of Technology Ethics Committee on the  
17th March 2014 AUTEK Reference number 14/53

## Appendix VIII: Skier type to determine ski-binding release settings

### ISO 11088-06 € standard definition of skier type

	Skier Type 1	Skier Type 2	Skier Type 3
Speed	Slow to moderate	Skiers that do not meet the descriptions of either 1 or 3	Fast
Terrain	Gentle to moderate		Steep
Style	Cautious (or undetermined)		Aggressive

### F 939-06 standard example of skier type classification poster

Skier Type 1	Skier Type 2	Skier Type 3
Cautious skiing on smooth slopes of gentle to moderate pitch	Skiers not classified as Type I or III	Fast skiing on slopes of moderate to steep pitch
Skiers who designate themselves as Type I receive lower than average release/retention settings. This corresponds to an increased risk of inadvertent binding release in order to gain release-ability in a fall. This type also applies to entry-level skiers uncertain of their classification.	Skiers who designate themselves as Type II receive average release retention settings appropriate for most recreational skiing.	Skiers who designate themselves as Type III receive higher than average release/retention settings. This corresponds to decreased release-ability in a fall in order to gain a decreased risk of inadvertent binding release. This classification is not recommended for skiers 47 lb (27 kg) and under.

AFNOR standard definition of skier type

Skier Type -1	Skier Type 1	Skier Type 2	Skier Type 3	Skier Type 3+
Beginner less than 7 days of practice	Young beginner, with a poor physical condition	Good young skier, elastic and fluent style, all ski runs	Good skier aggressive skiing on all terrains	Excellent skier on dangerous abrupt slopes
	Intermediate level in poor condition <hr/> Good adult, flowing, fluid style, without aggressiveness, favouring safety	Coping level, good physical condition, but imperfect style, with frequent regain of balance	Frequent regaining of balance	Aggressive skiing on all runs with bad experience of the adjustment corresponding to type 3 (inadvertent release without necessity)

## Appendix IX: Codes of conduct

### Federation Internationale de Ski (FIS) skier's code of conduct

#### **Basic Rule:**

1. Respect others. Do not endanger or prejudice anyone.

#### **Moving Rules:**

2. Move in control, adapt your manner of skiing and snowboarding and speed to your ability and the conditions.
3. Do not impede the route of the skier and snowboarder in front of you.
4. Take a wide berth when overtaking.
5. Look up and down the slopes before entering the piste, starting and moving upwards to ensure that you are not endangering anyone.

#### **Stopping/climbing:**

6. Only stop at the edge of the piste or where you can be seen easily.
7. When climbing up or down keep to the side of the piste.

#### **Signs:**

8. Obey all signs and markings.

#### **Actions in the case of accidents:**

9. Provide help and alert the rescue service.
10. If involved or a witness, you must state your name or address.

## New Zealand Snow Users Responsibility Code

### **1. Stay in control at all times**

Know your ability, start easy, be able to stop and avoid other people. Losing control is the number one cause of falls.

### **2. People below you have the right of way**

The skier or boarder downhill of you has the right of way. Don't forget to look above before entering a trail.

### **3. Obey all ski area signage**

Signs are there for your safety. Keep out of closed areas.

### **4. Look before you leap**

Scope out jumps first. Ensure the area is clear of others and use a spotter on blind jumps.

### **5. Stop where you can be seen**

When stopping, try to move to the side of the trail and make sure you can be seen from above.

### **6. Don't lose what you use**

Equipment must be secured while walking or stashing. This goes for rubbish too!

Remember to take all your waste with you so it doesn't become a hazard for others (or the environment).

### **7. Stay on scene**

If you are involved in or witness an accident, remain at the scene and identify yourself to the ski patrol.

### **8. Respect gets respect**

Right from the lift line, to the slopes, and through the car park - treat others as you would want to be treated.

## Appendix X: Strategy development surveys

### SURVEY MONKEY I

1. What are your three top safety concerns in terms of ski area users?
  2. Where do you think the biggest gains can be made in terms of injury prevention?
  3. What are your five top suggestions for changes to the snow users' responsibility code?
  4. What is the most effective way to communicate with your customer base?  
Rate the effectiveness of the communication mediums listed below:  
In-person; during lessons; educating groups prior to visiting the ski area; ski area website, Facebook; video in mountain café; posters; billboards; email; TV adverts; any all-day mountain event; Snowsports Council website; ACC website; Mountain Safety Council website; radio adverts; injury prevention all day events; inflight video; Twitter
- | Least effective | Reasonable | Moderately | Most |
|-----------------|------------|------------|------|
| 1               | 2          | 3          | 4    |
5. What other ideas do you have regarding effective communication?
  6. Do you use the NID to record and analyse ski area accidents?
  7. If you use the NID how can the system be improved?
  8. How often do you analyse NID data?
  9. Are there any areas of particular interest regarding injury prevention you would like more research?
  10. What percentage of ski area incidents do you feel are actually preventable?

## SURVEY MONKEY II

Please indicate your text preferences for the new snow safety code in the table below.

	Yes	No	Maybe-rewrite	No response
Stay in control at all times				-
Respect gets respect				
Stay injury-free				
Obey ski area signage, it's for your safety				
Obey the signs				
Ride to the conditions and your ability				
Chose terrain that matches ability				
Know your limits, choose terrain that matches your ability				
Know your limits				
Control your speed				
Control your speed in congested areas				
Don't lose what you use, equipment or rubbish				
Don't lose what you use				
Share the slopes and give others space				
Share the slopes, give way to others				
Give way to riders below				
Give way to people below				
Wear protective equipment				
Protect your head (and wrist if less than 30 days riding)				
Protect your head, wear a helmet				
Protect your wrist, wear a wrist-guard				
Use correctly set-up equipment				
Use recently serviced equipment				
Snow sports are physically demanding, drink and eat regularly				
Reduce exhaustion, drink and eat often				

## Appendix XI: SAANZ safety signs

### Trail Signage

**Green circle:** signifies **easiest terrain** suitable for BEGINNER skiers/boarders.

**Blue square:** signifies **more difficult terrain** suitable for INTERMEDIATE skiers/boarders.

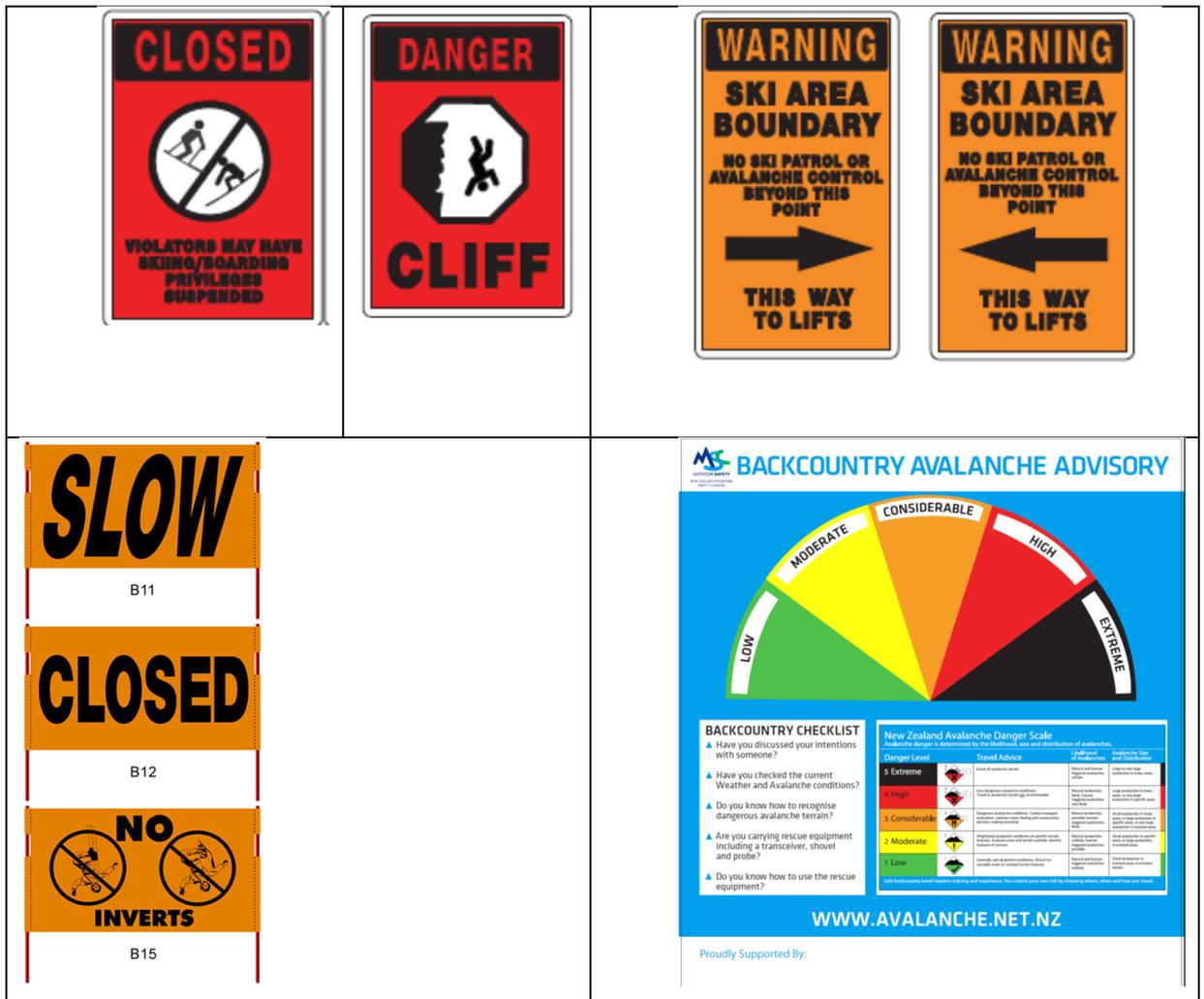
**Black diamond:** signifies **most difficult terrain** suitable for ADVANCED skiers/boarders

Note: Black diamond (most difficult) runs are not usually signposted or fenced.

Two black diamonds "extreme" runs not suitable for most recreational skiers.

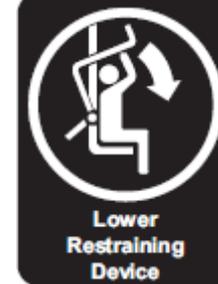
### Key Safety Signs





**Lift Signs**

Sign	Pictogram	Sign	Pictogram
<p>All lifts (at loading area)</p> <p>If unfamiliar with use of lift ask attendant for instructions before loading area</p>	<p>If Unfamiliar With Use Of Lift Ask Attendant For Instructions</p>	<p>Keep tips up (Ahead of any points where tips can come into contact with a platform or snow surface)</p>	<p>Keep Tips Up</p>

<p>Remove pole straps from wrists before loading area</p>	 <p><b>Remove Pole Straps From Wrists</b></p> <p>GH – Just on surface lifts?</p>	<p>Prepare to unload (Distance to be indicated in metres at bottom of sign and direction left/right to be indicated by an arrow, before the unloading area)</p>	 <p><b>Prepare to Unload XXX m</b>      <b>Prepare to Unload XXX m</b></p>
<p>Secure loose items before the loading area</p>	 <p><b>Secure Loose Items</b></p>	<p>Raise restraining device before the unloading area</p>	 <p><b>Raise Restraining Device</b></p>
<p><b>Chairlifts</b> Lower Restraining Device (On first or second tower)</p>	 <p><b>Lower Restraining Device</b></p>	<p>Unload Here (Direction left/right to be indicated by an arrow at the unloading area)</p>	 <p><b>Unload Here</b>      <b>Unload Here</b></p>
<p>Do Not Swing Or Bounce Chairs (On first or second tower)</p>	 <p><b>Do Not Swing Or Bounce Chairs</b></p>	<p>Safety Gate Emergency Stopping Device (Where applicable, a red flag shall be attached to the</p>	 <p><b>Safety Gate Emergency Stopping Device</b></p>

		safety gate or cord, at the safety gate area)	
Surface lifts Stay In Track (Along the track)		Safety Gate Emergency Stopping Device (Where applicable, a red flag shall be attached to the safety gate or cord, at the safety gate area)	
Fallen Skier Clear Track Immediately (Direction left/right to be indicated by an arrow, along the track)		Do Not Straddle T-Bar (After the loading area)	
Prepare To Unload (Distance to be indicated in metres at bottom of sign and direction left/right to be indicated by an arrow, before the unloading area)		<b>Additional sign for conveyors</b> Remain Standing At All Times	

<p>Unload Here (Direction left/right to be indicated by an arrow at the unloading area)</p>	 <p>The sign features a white circle containing two white arrows pointing in opposite directions (left and right). Below the circle, the words "Unload Here" are printed in white on a black background.</p>	<p>Safety Gate Emergency Stopping Device (Where applicable, a red flag shall be attached to the safety gate or cord, at the safety gate area)</p>	 <p>The sign features a white circle containing a white symbol of a hand with a red flag pointing to the left. Below the circle, the words "Safety Gate Emergency Stopping Device" are printed in white on a black background.</p>
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