

A REVIEW OF INJURY
COUNTERMEASURES AND THEIR
EFFECTIVENESS FOR ALPINE SKIING

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Title and sub-title:

A review of injury countermeasures and their effectiveness for alpine skiing

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Abstract:

Alpine skiing is a popular sport that requires specific equipment. The technological aspects of this equipment and the associated injury patterns have changed over time. Skiing is also physically demanding and requires strength, flexibility, endurance, good anticipation and reflexes. Skiing is undertaken in conditions and an environment that change throughout the day and from one day to the next. The skier, ski equipment and the environment all play a role both in the occurrence of injuries and their prevention. The most commonly injured body regions are the upper extremity, thumb, knee, and ankle and lacerations are common. The objective of this report is to present a critical review of the extent to which countermeasures for preventing alpine skiing injuries have been formally evaluated and demonstrated to be effective. In particular, the results of these evaluations and the level of supporting evidence were considered. The review has found that the evidence for countermeasure effectiveness is generally based on a combination of epidemiological studies, biomechanical evidence or testing of equipment, and informed opinion or anecdotal evidence. Very little evidence is based on controlled trials or the actual evaluation of countermeasures 'in the field'. The review also highlights areas that need more formal evaluation, those that warrant more immediate attention and action and those in which recommendations for progress in injury reduction could be made now on the basis of existing evidence. Finally, recommendations for further action in injury prevention research and practice are given. Recommendations for further countermeasure research, development and implementation are presented for each countermeasure separately and include the need to conduct further biomechanical and epidemiological research to determine injury mechanisms, continued monitoring of injury trends over time, further development and testing of equipment, the need to conduct controlled evaluations with representative skier populations, assessing the effectiveness of ski lessons and other forms of skier education, and ongoing injury surveillance, etc. This report also recognises the initiatives already undertaken by individuals and ski organisations, the available research and its findings and limitations, the improvements that can be made, and the opportunities for further research into and development of injury countermeasures. In doing so, it provides a basis for further action in injury prevention research and practice in the sport of alpine skiing.

Key Words:

alpine skiing, downhill skiing, injury prevention, countermeasures, evaluation

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EXECUTIVE SUMMARY

1. INTRODUCTION

Skiing is a popular sport for which there is a broad range of ages and standards among skiers, as well as skiers with various types of disability. According to the Alpine Resorts Commission, 10-12% of the population participates in skiing. The true level of 'real' skiers (ie excluding casual skiers) is likely to be closer to 5%, with an annual growth rate of 1.5%. Alpine skiers account for the majority (75%) of participants in alpine sports.

Commercial development of skiing has progressed since the mid-1950s. Skiing is a sport that requires specific equipment. The technological aspects of this equipment and the associated injury patterns have changed over time. Skiing is also a physically demanding sport that requires strength, flexibility, endurance, good anticipation and reflexes. Skiing is undertaken in conditions and an environment that change throughout the day and from one day to the next. Whilst this is part of the beauty of the sport and the experience of being in the mountains, skiers may not be adequately prepared for these changes. Due to its very nature, skiing may always entail a degree of risk of injury. The skier, ski equipment and the environment all play a role both in the occurrence of injuries and their prevention.

The main sources of general skiing injury data in Australia are those collected by the Ski Patrol. On the basis of Victorian Ski Patrol records, injury rates are estimated to be between 1.5 and 3.9 injuries per 1000 visitor days, and thus are comparable to the international mean of 3.65 per 1000 skier days. The rates of some injuries have changed over time and have been influenced by a number of factors including improvements to equipment design. There is nonetheless room for improvement in injury prevention, building on the initiatives already undertaken by skiing organisations and individuals.

Australian skiing injury data identifies six major injury categories (upper body, thumb, knee, fractured tibia, ankle and lacerations). Injuries to the head, although less frequent, can be particularly severe. The rates of four of the injury categories showed a significant trend over the period 1987-1992: the knee injury rate increased; the rate of tibial fractures decreased as did the rate of ankle injuries and lacerations; upward trends in injury rates for the upper body or thumb were not significant.

Measures to prevent or control injury, otherwise known as countermeasures, can be targeted toward primary (pre-event), secondary (event) and tertiary (post-event) prevention in the chain of events leading to injury. Key injury countermeasures for alpine skiing are summarised in the following table. There is often a multitude of factors that contribute to the risk of injury in skiing. Generally, more than one factor is involved in each injury.

For each countermeasure, or set of similar countermeasures, the epidemiological basis and rationale for its use in injury prevention is presented in this review. A critical review of the evidence for its effectiveness in the prevention of skiing injuries and recommendations for further countermeasure research, development and implementation have also been provided. Anecdotal evidence or informed opinion is considered to be the weakest of the evidence available. Whilst not discounting the value of informed opinion, evidence from biomechanical studies, testing of equipment, or data-based studies, carries greater scientific weight. Stronger still is evidence gained from controlled evaluations conducted in the field. Finally, evidence of consumer opinion or acceptance is important in the implementation and institutionalisation of injury countermeasures. The review highlights areas that need

more formal evaluation, those that warrant more immediate attention and action and those in which recommendations for progress in injury reduction could be made now on the basis of existing evidence.

Countermeasures for alpine skiing injuries

| Level of prevention | Countermeasures |
|-----------------------|---|
| Primary (pre-event) | <ul style="list-style-type: none"> • Pre-season conditioning and fitness programs • Adequate warm ups • Equipment factors (eg, skis, boots, bindings, ski poles, eyewear, clothing, helmets) • Professional adjustment of ski bindings • Adherence by skiers to the skiers' safety and courtesy codes • Ski patrollers and speed control measures • Environmental factors (eg, condition of ski slopes, marking or protection of natural obstacles, resort features or lifting equipment, design of ski runs and trails) • Grading of ski runs (green, blue and black) and run closure where necessary • Prevention of skier congestion and overcrowded slopes • Skier education programs • Skiing instruction and expertise of instructors • Adequate supervision of children • Use of safety equipment |
| Secondary (event) | <ul style="list-style-type: none"> • Condition of ski slopes and environmental factors • General sports equipment (ski pole handle design, adequate binding adjustment, ski boots) • Skiers' conduct code and speed control • Protective equipment (helmets, eyewear, ski brakes) |
| Tertiary (post-event) | <ul style="list-style-type: none"> • Availability of first aid equipment • Ski patrol assessment, treatment and transport • Prompt access to medical care • Rest, Ice, Compression, Elevation, Referral of injuries • Adequate treatment and rehabilitation of injuries before resumption of skiing |

2. SKI POLE HANDLE AND SKI GLOVE DESIGN

Upper extremity injuries account for about 17-25% of all skiing injuries and injuries to the thumb are the most common upper extremity injury. Ski pole handle design has been implicated as a major factor in these injuries. Alternatively, the thumb coming into contact with the snow during a fall may be a factor.

This review identified four studies which provided evaluations of ski pole handle design and one that described ski glove design. Of the studies evaluating ski pole handle design, all provided data-based evidence and two provided a detailed examination of equipment design. None of these studies provided a controlled evaluation of these countermeasures. On the basis of these studies, the weight of evidence suggesting that any particular handle design or method of holding the strap would have a major influence on the likelihood of injury is weak. Similarly, there is not strong evidence for a significant contribution to injury prevention if all skiers were to use a certain design of ski pole handle or hold their ski poles in a particular way. There were, however, methodological problems with some of the studies and the results were not always clearly presented.

Innovation in design or biomechanical testing and evaluation in relation to this countermeasure does not appear to have been developed to the same extent or to have received as much attention as other countermeasures such as the functional unit of the ski/binding/brake/boot system. This suggests that there is still scope for further development and improvement. Newer types of handle design may have the potential to result in fewer thumb injuries. However, their evaluation in controlled trials or their use by skiers in the epidemiological studies reviewed here has not been sufficient to provide clear evidence of their potential for injury prevention.

A ski glove designed to eject the ski pole from the skier's hand during a fall, was an innovative approach to the problem of thumb injuries, but has yet to be evaluated. There has also been no formal evaluation of improved falling techniques or pre-season exercises for strengthening thumb musculature.

Recommendations for further research, development and implementation

- Further detailed research into the mechanisms of thumb injuries is required to target further appropriate countermeasure development. This could be achieved by conducting interviews with skiers with injured thumbs, to determine the actual sequence of events that led to their injury.
- Further epidemiological and ergonomic research into the design of ski pole handles and ski straps is needed.
- Further biomechanical and developmental research into the design of ski gloves is required.
- Controlled epidemiological evaluations of both ski pole handles and ski glove designs in the field are required.
- An assessment of correct falling techniques and consideration of what is taught by ski schools in relation to these should be made.
- There should be continued support for a high standard of ski patrol services to provide a rapid response and safe transport of injured skiers.
- Specific advice, or training, for doctors in and around ski field areas, about the examination, management and rehabilitation of thumb and shoulder injuries needs to be developed and promoted.

3. SKI BINDINGS AND ASSOCIATED FACTORS

Knee injuries are the most common site of injury, accounting for between 20 and 32% of all alpine skiing injuries. Inadequate release of ski bindings has been implicated in lower limb injuries. The ski release binding is the mechanism that attaches the boot to the ski. Forces are transmitted through the lower limb and ski boot to the binding mechanism or vice versa. Ski bindings should release in response to transmitted forces in time to prevent injury to the skier, but not 'prematurely'. Binding release performance may be influenced by factors such as inadequate or non-professional adjustment, icing of bindings in extreme weather conditions and the condition of the ski boot sole.

The articles reviewed here were related to the study of the biomechanics of ski bindings and their release in response to various loads and loading patterns. Other studies have looked at the contribution of bindings and their release to lower extremity equipment-related injuries, the effect of various methods of binding adjustment, and the determinants

of skiers' behaviour in getting their bindings adjusted professionally. Another study reviewed computer controlled release binding prototypes constructed for biomechanical testing purposes, and were not commercially available bindings. Unfortunately, many of the identified studies were over 10 years old since little current information or recent studies could be identified in this review. The relevance of these studies to today's equipment may therefore be questionable, given the changes in ski equipment over the past 10 years.

A total of fourteen studies was identified in this review. All but one of these studies focussed on equipment design. Six studies reported a data-based evaluation of ski bindings and only one study involved a controlled trial. One study considered skiers' acceptance of an electronically controlled binding system that they carried with them. The weight of evidence suggests that current bindings do not address sufficiently well the multi-directional release required to reduce the risk of lower limb, and especially knee, injuries and that further technical developments and innovations are required. The standard of bindings and boots also needs to be considered.

Optimal adjustment of bindings using a testing device has been shown to be associated with a reduced risk of lower extremity injury. The adjustment of bindings that are in use has been shown to be inadequate, especially in the case of children's bindings. Adjustment by the binding scale on the binding itself is not likely to be sufficiently accurate. For an accurate adjustment, use of a testing device by adequately trained personnel is essential. This testing should be standardised and performed regularly. There is also room for improvement in the field of international standards.

Recommendations for further research, development and implementation

- Continued research into, and development of, multi-directional release bindings.
- Ongoing evaluation of current ski binding designs.
- Case control studies to evaluate the methods for, and the effectiveness of the different methods of binding adjustment.
- Australian studies on the adequacy of skiers' binding adjustment in both children and adults.
- Particular attention needs to be given to standards for, and adjustment of, children's boots and bindings.
- Retailers and hiring outlets should obtain and use mechanical testing devices for achieving the required DIN settings.
- Regulations and standards for ski shops and ski hire outlets dealing with the training of personnel and the use of mechanical testing devices should be implemented, where they are not already in place.
- Investigate the role of skier education to improve knowledge about the importance of ski bindings.
- Improved skier education about binding release and adequate adjustment needs to be achieved.
- Various modes of skier education need to be tested to determine which is the most effective approach (eg pamphlets on arrival at the slopes, promotional campaigns on the slopes, etc).

4. SKI BOOTS AND SKIS

Ski boot technology has developed over the last 25 years from lace up leather boots to moulded plastic boots. Ski boots provide support for the foot, ankle and lower leg and assist in transmitting forces from the skier to the binding system and vice versa. The stiffness of the boot has also been associated with injury and boot top fractures.

Many theoretical or biomechanical studies have been done on ski bindings but few on the effectiveness of ski boots for preventing injury. The studies reviewed here relate to case studies of boot top fractures, investigations of boot stiffness and boot shaft characteristics, and analysis of the pain threshold of the lower leg and the effect of temperature on this. Four studies have looked specifically at the role of ski boot design as a measure to prevent ski injuries. Each of these studies involved biomechanical/equipment testing and provided some further informed opinion on the role of boot design. Unfortunately, there has been little formal evaluation of boot design as a countermeasure in injury prevention and how this relates to boot stiffness characteristics and pain threshold. The available evidence is based more on informed opinion, than formal trials or tests. Boot characteristics, such as individualised fit and comfort, temperature isolation, and lack of pressure areas are obviously important and, logically, can be expected to help prevent thermal or mechanical injury. The role of ski boot design in the transmission of forces and appropriate binding release is less well investigated, as is the role of the boot in prevention of ligamentous knee injuries. Boot characteristics and choice need to be considered in association with the ski/binding unit as has been recommended. The standard of children's boots and equipment in general needs attention.

Recommendations for research, development and implementation

- Further research into the characteristics of boot design that are relevant to comfort and reduction of lower leg and knee injury.
- Formal evaluations of boot design as a countermeasure in the reduction of injury.
- There needs to be more attention given to the design and standard of children's ski boots.
- Future boot specifications should address differences between men and women (and children).
- The role of consumer education about ski boot design and function in relation to injury prevention needs investigation.
- Data about lower extremity injuries in telemark skiers should be collected and compared with that of alpine and cross-country skiers.
- An epidemiological study to determine any associations between 'hired' versus 'owned' skiing equipment and injury risk needs to be undertaken.

5. SKIER ATTITUDES, KNOWLEDGE AND BEHAVIOURS

Technological developments in ski equipment, standardisation of professional testing of ski bindings, and optimal adjustment of ski bindings have been recommendations earlier in this review. Skiers' attitudes, knowledge and behaviours regarding injury prevention are another important aspect of implementing countermeasures. Thus an understanding of these factors, including any barriers, is important in assisting the promotion of preventive measures. Unfortunately, methods for achieving this have not been extensively researched.

Recommendations for research, development and implementation

- A study of Australian skiers' attitudes, knowledge and behaviours in relation to risk factors associated with skiing injuries is required.
- The results of this study should be used as a basis for educational and injury prevention programs, and promotion of injury prevention countermeasures among Australian skiers.
- Research into different strategies or modes of educational delivery should be explored.
- A review of health promotion programs and adoption of injury prevention countermeasures should be conducted. This should include the experiences of other sports that may be relevant to skiing.

6. PRE-SEASON CONDITIONING

Skiing is a physically demanding sport that requires muscle endurance, strength, flexibility and cardiopulmonary fitness. Whilst highly trained athletes (racers) and experienced skiers have injuries, the recreational skier with low skills and inadequate physical preparation may be at greater risk. Approaches to the study of the effectiveness of preseason conditioning in the reduction of skiing injury face methodological difficulties, particularly with respect to retrospective self-assessment/reporting and validity. It is also possible that the general recreational skiing population may not accept the requirements of a rigorous training program that may have a more substantial and measurable impact on the reduction of injury rates. Expert and informed opinion is in favour of pre-season conditioning, and such conditioning should not be discouraged, but its effectiveness in preventing injury has not been formally evaluated.

Recommendations for research, development and implementation

- Additional research into the effectiveness of conditioning programs on the prevention of skiing injuries is required.
- A more rigorous evaluation of the impact and health outcomes of the Australian Physiotherapy Association's "Get Fit to Ski with Physiotherapy" program should be undertaken.

7. SKI LESSONS

Ski lessons are available at most Australian resorts, and certainly at the major ones. The role of skiing instruction in preventing injuries is considered controversial, and it has been argued that skiing lessons must be coupled with experience to have a positive effect. It is also argued that ski instructors should put more emphasis on proper functioning of equipment and teaching proper falling techniques .

A number of epidemiological studies of injuries among skiers have considered the association of ability, and sometimes a history of having taken ski lessons, with injury rates. Difficulties in interpreting the results, and weighing up the evidence, lie in the reliability of self-reported of ability and a lack of consistency (or definition thereof) in the categories used to report ability and the history of ski lessons. The weight of evidence suggests that beginners and less experienced skiers have a higher risk of injury than advanced or intermediate skiers. The effect of ski lessons on the injury rates of intermediate or advanced skiers is less obvious. Ski lessons may assist in reducing the risk

of injury, and do so by increasing a skier's ability more quickly than if the skier did not take lessons.

The effectiveness of ski lessons as a countermeasure, however, has not been evaluated in a formal, controlled way and neither has the specific content of ski lessons. In fact, little of the evidence is to do with lessons. Most relates to levels of competence, which are assumed to be associated with lesson taking.

Recommendations for research, development and implementation

- The categorisation of skiing ability and history of ski lessons should be standardised in future studies.
- Controlled studies to evaluate the effectiveness of ski lessons for injury prevention should be undertaken.
- A review of the content of ski lessons with respect to skiing safety should be undertaken.

8. CLOTHING, INCLUDING EYEWEAR AND SKIN PROTECTION

Clothing serves several purposes in alpine conditions, including protection from a variety of weather conditions such as snow, sleet or rain, high winds, poor visibility, brilliantly sunny days and strong reflective glare. Skin and eye protection from direct or reflected sunlight are essential even on cloudy days. Ultra-violet protection is particularly important at high altitudes. Because appearance and comfort are important, this is an area that warrants particular attention to consumer acceptance.

Recommendations for research, development and implementation

- Continue to improve the materials for skiing garments and eyewear.
- Development and further testing of clothing with higher coefficients of friction should be considered.
- Continue to reinforce the essential and protective aspects of clothing to skiers.
- Continue to encourage the use of protective sun screen.
- Consider a specific review of children's clothing and eyewear.

9. SPEED AND COLLISION CONTROL

Speed and loss of control have been implicated in injury. Skiing too fast and out of control or on terrain above a skier's ability can increase the risk of injury. High energy and direct impact falls or collisions have been associated with serious injuries. These may result from collisions at speed, with natural obstacles such as rocks, trees, ski lift or resort equipment, other skiers or persons on the slope, or as the result of a fall in firm or icy conditions.

Collisions may occur where slopes intersect. The separation of ski runs and slope management have been highlighted as countermeasures. Collisions with hazards including lift and resort equipment such as snow making or grooming machines, suggests a greater need for the adequate identification of such hazards and the provision of protective padding where necessary.

No studies were identified that formally evaluated speed and collision control. Nevertheless, the review of epidemiological studies in the introduction to this section has substantiated speed and collision as risk factors for major trauma and injuries to the head, spine and nervous system.

Recommendations for research, development and implementation

- Skier education programs relating to safe skiing should continue or be increased.
- Consideration should be given to determining the most effective means of prevention high speed incidents and collisions.
- Skier education programs should be targeted to certain groups (eg young males) and the hazards of reckless skiing.
- Speed control programs, at the discretion of ski patrollers, should be supported.
- Methods for evaluating the effectiveness of speed control programs should be explored and built into routine ski patrol activities.
- Improved ways of reducing the potential for injury from lift and resort equipment should be considered.

10. PROTECTIVE HEADGEAR

Expert and informed opinion suggests that properly designed protective headgear should help protect against head injuries. The use of such headgear may be appropriate to all skiers or more so for certain groups of recreational skiers such as children. As a countermeasure for injury prevention in skiing, the effectiveness of protective headgear has not been formally evaluated. It has been suggested that current helmet design may interfere with vision and hearing, which may result in cues that are important to skiers in the prevention of collisions being lost to skiers. However, there is no formal proof that this should be the case. Indeed, modern helmets provide perforations or holes for the ears to assist with hearing. The cost, comfort, colour and design are features that may influence consumer acceptability. Risk factors such as speed, environmental hazards and skier behaviour need to be considered in any strategy or program to reduce head or cervical spine injuries.

Recommendations for further research, development and implementation

- Further research into the development and improved design of protective headgear is needed before it is widely promoted.
- The development of generic protective headgear that is adaptable to different sports should be endorsed.
- Research into skier's attitudes towards, and acceptability of protective headgear, should be undertaken.
- Once there is a suitable prototype available, controlled trials on the ski fields should be undertaken to determine the effectiveness of protective headgear.
- The development of standards for protective headgear should be considered.

11. ADEQUATE NUTRITION AND REDUCED ALCOHOL INTAKE

Controversy about surrounds the relationship between injury risk and alcohol use in alpine skiing. The weight of evidence suggests that levels of alcohol consumption in skiers are not clear, nor is the effect alcohol consumption may have on the risk of injury. The prevalence of measurable blood alcohol amongst skiers may be lower than expected. This has not been studied in Australian resorts. There are methodological difficulties associated with the estimation of blood alcohol levels in skiing. There are also practical difficulties in the measurement of blood alcohol concentration with a breath analyser in very cold conditions. The dangers associated with hypothermia in a mountain environment and the evidence of the effect of blood alcohol levels on coordination, concentration and reflexes in other research are well recognised. Given this, it would seem prudent to caution skiers to consider their alcohol intake and the potential effect it may have on skiing performance, and not to drink alcohol during skiing breaks.

The evidence suggests that adequate carbohydrate (and nutritional) intake and replenishment during and after skiing is important and to be recommended.

Recommendations for research, development and implementation

- Reinforce the importance of good nutrition and adequate carbohydrate replenishment during skiing.
- Conduct preliminary studies on the alcohol consumption patterns of Australian skiers to determine the extent to which may be a factor in injuries.
- Controlled studies on the relationship between alcohol consumption and skiing injury occurrence are needed - but these should be based on the results from the above recommendation.

12. STANDARDS FOR SKIING EQUIPMENT

The development of skiing standards began in America in 1972. Standards Australia has a policy of adopting an international standard wherever an appropriate one is available. In developing a new standard, a genuine need and the support of a community or interest group needs to be demonstrated.

Recommendations for further standards development

- A review of Australia's policy regarding skiing equipment and requirements in relation to equipment standards should be undertaken.
- A review of Australia's policy regarding training and standards for ski shop personnel, ski binding fitting and adjustment in retail and hire outlets, and the use of test devices for binding adjustment needs to be performed.
- Based on the results of these two reviews, Australian policies may need to be reviewed and revised.

13. SAFE LIFT EQUIPMENT

The development of ski resorts involves the installation of lift systems to take skiers, and downhill skiers in particular, to the top of ski runs. The type of lifts available include poma lifts, T-bar lifts, chair lifts, and gondola lifts of various sizes. There is generally little

information available on the injuries associated with ski lifts, and no studies that compared injuries between different types of lifting systems. The process of getting on and off lifts is an event that could well be associated with falls or injury. How smoothly it goes can depend on the ability of the skier, the type of lift, maintenance of the area for getting on or off the lift, the instructions and assistance provided to skiers from lift attendants, and the ability of the other skiers who may be travelling on the lift at the same time in the case of T-bars or chairlifts. Skiers can also collide with lift towers, which need to be adequately visible and padded as necessary.

Recommendations for further development, research and implementation

- Further research into the extent of lift associated injuries and how to minimise them is needed.
- Data on lift associated injuries should be routinely collected as part of resort management or as part of ski patrol reports.
- Monitor injury rates at resorts where chair lifts have replaced T-bars and drag lifts to determine the impact on injury rates.

14. ENVIRONMENTAL CONDITIONS

Many of the hazards of skiing will never be completely removed from the sport, and to do so may detract from the aesthetic beauty of the skiing in the mountains or the appeal of skiing as a vigorous adventurous sport. Some potential hazards such as ski lift towers are an unavoidable component of the resort structure, and trees provide shelter, protection against erosion, natural beauty and reference points in poor visibility. It is generally accepted by skiers and the ski industry that it is the skier's responsibility to ski in a responsible manner, to visually assess the slope and snow conditions below them, and decide whether or not he or she has the skills necessary to successfully negotiate the slope. However, potentially hazardous slope conditions may not be visible simply by looking down the slope from above.

A consistent policy of hazard mitigation is important, for both skiers and the ski industry, in any program to reduce skiing injuries. Trail design, removal of obstacles, summer grooming and winter slope grooming are all important measures to help prevent injuries.

Recommendations for further research, development and implementation

- Pilot testing of a procedure for the calculation of injury severity scores and corrected injury severity scores to aid in ongoing assessment of slopes.
- More formal evaluation of the effectiveness of hazard identification and mitigation in injury reduction is needed.
- Standardisation of policies and methods for hazard identification and mitigation

15. SKI PATROLLERS, FIRST AID ON THE SKI SLOPES and general RESORT SAFETY

The organisation of emergency services, selection and maintenance of equipment, administration of first aid treatment, transport and the use of trained personnel have been identified as important aspects of a first aid service for skiers. The Ski Patrol plays a

valuable role in Australian alpine sports safety, with both professional and trained volunteer patrollers.

Ongoing injury surveillance by ski patrollers can identify slopes or trails where a number of injuries have occurred and assist in focusing hazard identification and mitigation and injury prevention. Action may involve advice to resort management, a speed control program, promotion of safety helmets, trail or ski run closure, signage or obstacle markers or avalanche danger control. Ongoing surveillance can also assist in evaluating the effectiveness of interventions.

Recommendations for further research, development and implementation

- Review the incident/injury report forms used by ski patrollers to maximise the use of information for injury research and monitoring.
- Consider methods for the collection of injury severity data and the potential for standardisation of this.
- Standardise data collection by ski patrollers and all Australian ski resorts.
- Standardise the age groups used for statistical comparisons in the analysis and reporting of injury data.
- Further develop injury surveillance programs for a range of snow sports
- Continue to support for the Ski Patrol Association.
- Make available of at least one GPS unit at all ski resorts
- Continue to promote safe driving in the mountains.

16. CONCLUSION

This review has found that the weight of evidence for countermeasure effectiveness is generally based on a combination of epidemiological studies, biomechanical evidence or testing of equipment, and informed opinion or anecdotal evidence. Very little evidence is based on controlled trials or the actual evaluation of countermeasures ‘in the field’. Similarly, very little research has assessed consumer opinion. No economic evaluations of skiing injury countermeasures or studies of the cost of skiing injuries were identified.

Skiing is a wonderful sport that can enjoyed by a wide variety of age groups and abilities. As a sport, skiing is growing in popularity and developing, but has a need for more controlled research on injury prevention. This review recognises the initiatives already undertaken by individuals and ski organisations, the available research and it's findings and limitations, the improvements that can be made, and the opportunities for further research into and development of injury countermeasures. In doing so, this review provides a basis for further action in injury prevention research and practice in the sport of alpine skiing.

1. INTRODUCTION

Alpine sports, including skiing, are growing in popularity in Victoria, Australia. The official season is from the Queen's Birthday weekend in June through to late September. Although participation in skiing has been estimated at 10-12% of the population, the true level of 'real' skiers is likely to be closer to 5%, with an annual growth rate of 1.5%. In comparison, about 8% of the population of the United States or Canada ski (Fetterplace, 1995).

Essentially there are two broad categories of skiing: alpine (or downhill) skiing and nordic (or cross-country) skiing. In reference articles, and in Australia generally, the terms downhill and cross-country skiing are more commonly used, respectively, and these will be used in this document. Snowboarding is another alpine sport that is popular with younger skiers and developing rapidly.

Resort surveys have estimated the breakdown of alpine sports participants to be alpine skiers (75%), cross-country skiers (20%) and snowboarders (5%) (Fetterplace, 1995). Within each of these sports there is a broad range of standards and ages of participants. The term 'recreational skier' will be used to define a person who is skiing in a non-professional capacity.

Commercial development of skiing has progressed since the mid-1950s, and skiing is an established sport enjoyed by over a million Australians every year (Sherry and Fenelon, 1991). Skiing is a sport that requires specific equipment. The technological aspects of this equipment and the associated injury patterns have changed over time. Skiing is also a physically demanding sport that requires strength, flexibility, endurance, good anticipation and reflexes. People with various types of neuromuscular, orthopaedic or sensory disability can also participate and compete in alpine sports.

Snow sports are undertaken in conditions and an environment that change throughout the day and from one day to the next. Whilst this is part of the beauty of the sport and the experience of being in the mountains, skiers may not be adequately prepared for these changes. Due to its very nature, skiing may always entail a degree of risk of injury. The skier, ski equipment and the environment all play a role both in the occurrence of injuries and their prevention.

There is considerable scope for injury prevention in terms of the equipment used by skiers and their ability, attitude and behaviour on the slopes. A considerable amount has been published on the epidemiology and biomechanics of skiing injuries with informed or expert conclusions on the contribution of equipment or skier behaviour. There is however a noticeable lack of formal, controlled evaluations of the effectiveness of injury prevention countermeasures in skiing. Consistent epidemiological surveillance of skiing injuries on a state and national basis is another important aspect of an injury prevention program.

2. AIMS

The overall aim of this report is to critically review both formal literature and informal sources that describe injury prevention measures, or countermeasures, for alpine skiing. In doing so, it provides an evaluation of the extent to which these countermeasures have been demonstrated to be effective.

Unlike other reports of alpine skiing, this report does not focus on the epidemiology of skiing injuries in detail. Rather, this report presents a detailed examination of the range of countermeasures promoted to prevent such injuries. However, a brief overview of the epidemiology of skiing injuries, particularly from an Australian perspective, is given to set the scene for the subsequent discussion of countermeasures.

In this report, the countermeasures discussed are widely promoted to prevent alpine skiing injuries. Detailed reviews of the countermeasures to prevent cross-country skiing and snowboarding injuries can be found elsewhere (Kelsall and Finch, 1996a; Kelsall and Finch, 1996b).

3. METHODOLOGY

The sources of information used to compile this report were:

- Medline CD-ROM for published medical literature (over the past 10-15 years)
- Sport discus CD-ROM search for published sports literature (over the past 10 years)
- injury conference proceedings scans
- information presented at the 1995 Alpine Safety Conference in Melbourne, November 1995
- discussions with key Australian researchers and sporting organisations
- correspondence with relevant state and national sporting organisations
- correspondence with relevant researchers registered by the National Sports Injury Research Centre
- a posting to the Injury List on the Internet
- Standards Australia
- world-wide standards index on CD-ROM 1995/96 issue. US Database: key words of helmet, sport, recreation
- information prepared by the Victorian Skiing Association
- NEXUS database scan on the keyword skiing
- scanning of other Internet and world wide web sites.

This review is based on English-language material only. It is acknowledged, however, that some of the European skiing injury information is published in other languages and that these articles have relevance to this report. Non-English language articles with English abstracts have been included in this review where appropriate.

The literature gathered for this review was critically assessed to determine the extent to which the various countermeasures had been fully evaluated and demonstrated to be effective in preventing injuries. A gradation scale for the strength of the evidence presented in the identified literature was developed. This is shown in Figure 1.

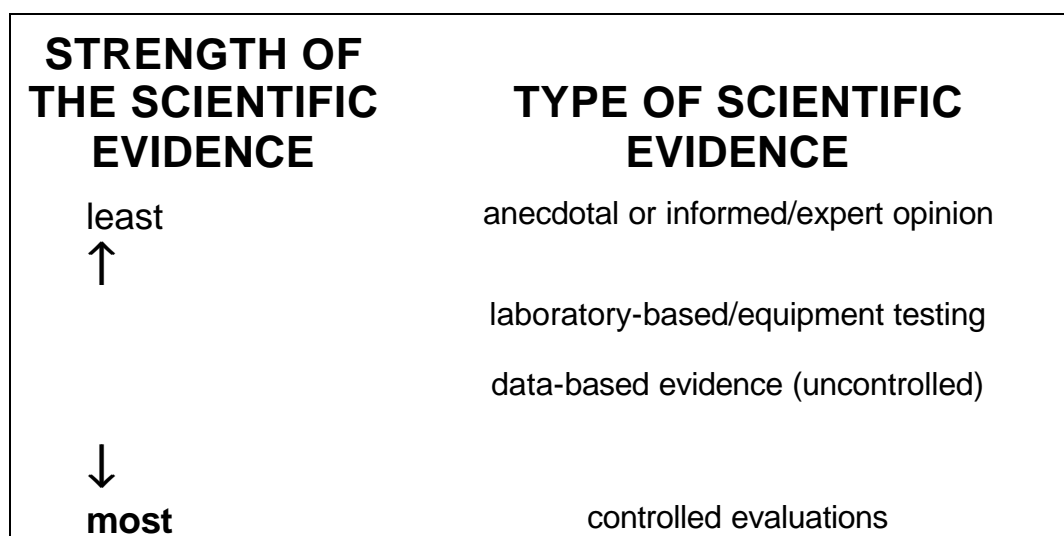


Figure 1: Grading scale for assessing the extent to which countermeasures have been fully evaluated

This scale reflects an epidemiological and rigorous scientific approach to injury prevention that considers demonstration of the effectiveness of a countermeasure’s performance in the field to be the highest level of ‘proof’. This is particularly important for sports injury countermeasures where any change to the nature of the sport is an important factor to be considered in their implementation. In general, changes to factors such as how the sport is undertaken/performed, the behaviour of the participants and the level of enjoyment can only be measured during ‘in-the-field’ evaluations.

At the lowest level of proof (ie the ‘least’ evidence end of the scale) are anecdotal reports of injuries and their prevention and comments based on informed or expert opinion. This category would include, for example, statements like “I treated five cases of concussion during last year’s ski season and all would have been prevented if they were wearing a helmet at the time” or “none of the children I treated last year had had their bindings properly adjusted before skiing”. Of course, some expert or informed opinion carries more weight than others, particularly when it is based on a critical review of available information.

Laboratory-based evidence is a very important source of information about sports injury countermeasures. This category includes reports that have explored equipment design and testing, development of standard testing procedures and biomechanical research, including that performed on animals, cadavers and simulated body tissue such as crash-test dummies. Such information provides detail about the extent to which countermeasures such as protective equipment and properly designed skiing equipment (eg bindings) perform under certain stress and/or impact conditions. This research is generally performed under laboratory conditions which are often controlled. However, such conditions may not be a good representation of actual environment or skiing conditions.

Data-based evidence can be of a number of forms. Case-series studies or routine surveillance systems document the incidence of new injury cases over periods of time. Patterns in data can be examined over time to draw conclusions about the value that countermeasures may have on injury rates. Cross-sectional epidemiological studies provide some information about injury prevalence at a given point of time but are unable to assess the influence of countermeasures on injury rates. Quasi-experimental studies are not

controlled evaluations but do enable a comparison of pre-intervention and post-intervention data to examine the effects of some countermeasures.

Controlled evaluations provide the most definitive evidence for the impact of countermeasures. Case-control studies and longitudinal (cohort) studies are common forms of controlled studies. Neither study type allows random assignment of people (or injuries) to test and control groups, though they are examples of natural experiments. A randomised controlled trial is considered to provide the best evidence. In such studies, the units of interest (ie the skiers, resorts, types of equipment, etc) are randomly assigned to test and control groups.

Another important aspect of countermeasure implementation is the extent to which they are accepted or adopted by the users for whom they were intended. Countermeasures should be acceptable to those they were designed to protect. Community consultation and awareness programs must therefore be considered in any implementation process. It is also important to assess barriers towards use of injury countermeasures and an examination of attitudes, knowledge and behaviours is crucial to this. Studies looking at these factors are generally conducted after implementation of a countermeasure and can highlight the need for behavioural or educational change at either the individual or organisational level. Because of the importance of this sort of research, the literature describing these studies is also included in this review.

Another measure of the success of countermeasures is a demonstration of their cost/benefit ratios. This information is often need by regulatory bodies and those involved in policy or rule making to inform their decisions about countermeasures. Unfortunately, studies of the economic benefits of sports injury countermeasures are rare, to date. Where they have been found, they have been included in this review.

For each countermeasure individually, the relevant literature has been critically reviewed. A matrix summarising the studies has been prepared for each countermeasure and these can be found in the Appendices to this report.

4. A BROAD OVERVIEW OF THE EPIDEMIOLOGY AND TRENDS OF SKIING INJURIES IN AUSTRALIA

Australian resorts and skiing conditions can sometimes be different to those of Europe or the United States (where most of the research has been done). This can sometimes make international comparisons of injury rates difficult. Equipment used in skiing in Australia, however, is similar to that used internationally and the countermeasures are comparable.

Ski patrol data collection and statistics are the main source of skiing injury data in Victoria and Australia. In Victoria, if a ski patroller is called to respond to an incident, the call is noted in a log book, and the patroller responds and tries to locate the person. The call is referred to as a 'dispatch' or a 'call-out'. If the person is not found or has moved on, the call is referred to as a 'stand-down'. If the incident or injury is minor and treated on the slope, no 'Ski Patrol Accident Report' form is completed. If the person needs further medical intervention, at the patroller's discretion, they are transported to the Medical Centre. A Ski Patrol Accident Report form is completed and this forms the basis of data collection. The patrollers' diagnosis recorded on this form is not corroborated by a final diagnosis.

On the basis of ski patrol records at Victorian resorts in 1994, skiing injury rates were estimated to be between 1.5 and 3.9 injuries per 1000 visitor days (Parfitt, 1995). In 1988, the rate was 2.4 injuries per 1000 visitor days or 1.9 per 1000 skier days (Fetterplace, 1995). The injury rate in Perisher Valley dropped from 10.9 per 1000 skier days in 1962 to 3.2 in 1988. Comparison of these rates, indicates a decline in skiing injuries over time in Australia. In fact, this was a statistically significant annual decline of 2.8% for the whole period (Sherry and Fenelon, 1991). The injury rates in Australia are similar to those reported internationally which vary from 0.8 to 9.1 per 1000 skier days with a mean of 3.65 per 1000 skier days (Lamont, 1991).

According to ski patrol records, approximately 400-500 people are transported to the Medical Centre at Mt Hotham resort each year. A further 100-200 minor incidents or injuries are treated on the slope. The 1995 "Summary-Resort Accident Statistics" are presented as the number of call-outs/1000 visitor days, the types of injuries, the numbers of cases requiring ambulance transport off the mountain and the number of fatalities. In the 1995 Victorian season there was an average of 2.8 callouts/1000 visitor days for all resorts (Alpine Safety Conference, 1995).

A 32-year study of skiing related deaths in the Snowy Mountains reported an overall incidence of 0.87 deaths per million skier days. This rate was broken down into 0.24 for trauma-related, 0.45 cardiac-related and 0.18 hypothermia-related deaths per million skier days (Sherry and Clout, 1988).

There are a number of difficulties in accurately comparing trends over time, between resorts and between countries. These include differences in the original populations from which the data was collected (eg ski patrol clients, patients at injury clinics, special surveys, etc) and in the denominator definitions (skier days or skier visits). The mix of injuries has altered more than the actual rate of injury over time. Injuries have shifted away from the lower limb towards the upper limb, shoulder and head. With respect to knee trauma, however, there has been an increase in ligamentous damage (Lamont, 1990; Johnson et al, 1989).

A recent analysis of Australian skiing injury trends was based on records of the Perisher Valley ski injury clinic (Sherry and Fenelon, 1991). Overall injury rates from 1962 to 1988 and specific injury rates for six injury categories (upper body, thumb, knee, fractured tibia, ankle and lacerations) were determined. The rates of four of the injury categories showed a significant trend: the knee injury rate increased; the rate of tibial fractures decreased as did the rate of ankle injuries and lacerations; upward trends in injury rates for the upper body or thumb were not significant.

The variable reporting of injury categories makes a definitive summary and direct comparisons difficult but the Perisher Valley summary of injuries due to downhill skiing 1987-1992 reasonably reflects the pattern (Coolahan et al, 1994). The contribution to the overall injury toll from each type of injury reported in this study is shown in Table 1.

Table 1 Common types of downhill skiing injuries at Perisher Valley

| Type of injury | Proportion of all reported cases |
|----------------------------------|---|
| knee sprains | 31.4% |
| lacerations to the head and face | 7.9% |
| lower limb fractures | 5.2% |
| sprained thumb | 5.2% |
| upper limb fractures | 4.5% |
| lacerations to the leg | 4.3% |
| dislocated shoulder | 4.2% |
| back/neck injury | 4.1% |
| concussion | 3.4% |
| shoulder sprains | 3.4% |
| ankle sprains | 2.4% |
| general bruising/haematoma | 9.9% |
| other | 14.0% |

(Source: Coolahan et al, 1994)

5. A BRIEF OVERVIEW OF INJURY COUNTERMEASURES FOR SKIING

Injuries are considered to result from a culmination of a set of circumstances and pre-existing conditions that may best be understood as a chain of events: pre-event, event and post-event (Robertson, 1983). Injury countermeasures are measures that can 'counter', prevent or reduce the risk of injury. A number of researchers have described how countermeasures can be targeted at the different links in the chain of events leading to injury (Haddon, 1972; Ozanne-Smith and Vulcan, 1990; Watt and Finch, 1996). Such injury countermeasures can be equated with primary (pre-event), secondary (event) and tertiary (post-event) prevention.

Primary countermeasures act before an event or incident that could lead to injury. That is, they prevent the injury from occurring in the first place. Table 2 lists some of the major primary (pre-event) countermeasures for alpine skiing.

Table 2 Primary (or pre-event) countermeasures

| |
|--|
| <ul style="list-style-type: none">• Pre-season conditioning and fitness programs• Adequate warm ups• Equipment factors (eg, skis, boots, bindings, ski poles, eyewear, clothing, helmets)• Professional adjustment of ski bindings• Adherence by skiers to the skiers' safety and courtesy codes• Ski patrollers and speed control measures• Environmental factors (eg, condition of ski slopes, marking or protection of natural obstacles, resort features or lifting equipment, design of ski runs and trails)• Grading of ski runs (green, blue and black) and run closure where necessary,• Prevention of skier congestion and overcrowded slopes• Skier education programs• Skiing instruction and expertise of instructors• Adequate supervision of children• Use of safety equipment |
|--|

Secondary countermeasures act during the event or incident to prevent the injury occurring or to reduce the severity of the injury. Table 3 summarises the secondary countermeasures for alpine skiing injuries.

Table 3 Secondary (or event) countermeasures

| |
|--|
| <ul style="list-style-type: none">• Condition of ski slopes and environmental factors• General sports equipment (ski pole handle design, adequate binding adjustment, ski boots)• Skiers' conduct code and speed control• Protective equipment (helmets, eyewear, ski brakes) |
|--|

Tertiary countermeasures act after the chain of events/incident leading to injury and help to minimise the consequences of injury. These tertiary countermeasures are summarised in Table 4.

Table 4 Tertiary (or post-event) countermeasures

- | |
|--|
| <ul style="list-style-type: none">• Availability of first aid equipment• Ski patrol assessment, treatment and transport• Prompt access to medical care• Rest, Ice, Compression, Elevation, Referral of injuries• Adequate treatment and rehabilitation of injuries before resumption of skiing |
|--|

There is a multitude of factors that contribute to the risk of injury in skiing. Generally, more than one factor is involved in each injury.

Skiing requires muscle endurance, strength, flexibility and cardio-pulmonary fitness. The average recreational skier may ski for a limited period of time each year, without adequate preparation and with resultant fatigue. Conditions in Victorian and Australian alpine resorts are variable, and often unpredictable and difficult, with, characteristically, icy conditions in mornings and late afternoons, and mid-afternoon 'soup' or 'slush'. On other occasions, conditions can be absolutely wonderful. Protective clothing and eyewear (ski goggles or sunglasses) are essential for all of these conditions. Collisions, particularly high speed ones, with objects such as trees, equipment or other skiers, have been implicated in the most serious injuries.

The forces transmitted through the boot/binding/ski system to the lower limb in turning or responding reflexively to loss of balance can be large. Fixation of the heel, the extended leverage of skis, the movements involved in skiing and falling, and the difficulty of ensuring bindings adequately retain or release the boot as required, leave the skier at risk of lower limb injuries. Historically, ski boots were lower and more flexible, resulting in fractures and sprains around the ankle. With the wide spread use of higher and stiffer boots, injuries have moved up the leg with an increase in the rates of twisting knee injuries and serious ligamentous damage, in particular. Binding release systems have improved but may never be able to meet the physical demands of skiing. These also need to be correctly adjusted.

The most common upper limb injury is to the thumb, particularly to the ulnar collateral ligament of the metacarpophalangeal joint (UCLMCPJ) of the thumb. This injury is likely to be significantly under reported in general skiing injury statistics. Ski pole handle design has been implicated as a major factor in these injuries.

In the forthcoming sections of this report, the literature assessing the effectiveness of the various countermeasures available for preventing skiing injuries given in Tables 2-3 is reviewed. For each countermeasure, the rationale for its use as a safety measure is presented together with a critical review of the extent to which it has been evaluated. Further details on the reviewed studies is provided in tabular form in the Appendices.

Although the countermeasures are expected to be effective for all recreational skiers, certain groups such as disabled skiers, children and mature skiers may have different requirements. For this reason, this report includes specific discussion of the nature on skiing injuries and their prevention in these particular groups.

6. DETAILED REVIEW OF ALPINE SKIING INJURY COUNTERMEASURES

This chapter provides a detailed review of each alpine skiing injury countermeasure. Each section begins with a description of the background and rationale for the countermeasure, including a brief description of the biomechanics of the particular injuries being prevented. A summary of the studies evaluating each countermeasure is presented. Full details of the studies can be found in the appendices. Finally, suggestions for further countermeasure research, development and implementation are given.

6.1 SKI POLE HANDLE AND SKI GLOVE DESIGN

6.1.1 Background

Upper extremity injuries account for about 17-25% of all skiing injuries (Carr et al, 1981; Engkvist et al, 1982; Fairclough and Mintowt-Czyz, 1986). Injuries to the thumb are the most common upper extremity injury in skiing. In one study of upper extremity injuries, 40% involved the thumb, and of these 80-85% included injuries to the ulnar collateral ligament of the metacarpophalangeal joint (UCLMCPJ) of the thumb (Carr et al, 1981). In other surveys, 60-71% of thumb injuries involved an injury to the UCLMCPJ (Engkvist et al, 1982; Fairclough and Mintowt-Czyz, 1986). These injuries can occur in all directions of fall, although a forward fall is more commonly reported (Carr et al, 1981; Engkvist et al, 1982).

Thumb injuries are rarely disabling at first and injured skiers often do not seek medical attention. This means that there may be considerable under reporting of these injuries in the formal statistics. A survey of skiers found that 23% had injured their thumb at least once, and only 27% of these had reported the injury (Carr et al, 1981). Optimal hand function for most daily living and sporting activities requires stability of the thumb and for this the UCL MCP joint prevents radial deviation. These injuries can carry a risk of disabling chronic injury if not treated adequately and some require surgery (Fricker and Hintermann, 1995).

The trauma mechanism for this type of injury is forced abduction and extension of the thumb. It is generally reasoned that retention of the ski pole in the hand during a fall is relevant to injury (Carr et al, 1981; Engkvist et al, 1982; Fairclough and Mintowt-Czyz, 1986; Ekeland and Nordsletten, 1994; Fricker and Hintermann, 1995). Rotation of the metacarpophalangeal (MCP) joint when the tip of the skier's thumb comes in contact with the snow has been proposed as a contributory factor (Lamont, 1989). Similar injuries in other sports that involve falls onto the outstretched hand are rare (Fairclough and Mintowt-Czyz, 1986). Such injuries sometimes occur in sports where there is direct ball to thumb contact (Fricker and Hintermann, 1995). Another suggestion is that the thumb is forced into an abduction/hyperextension position and in this position is jammed into the snow, leading to the injury (Fairclough and Mintowt-Czyz, 1986).

Countermeasures relevant to preventing upper extremity injuries include the design of the ski pole handle, the way the skier grips the pole, training skiers to discard poles during a fall (Morrissey et al, 1987; Fricker and Hintermann, 1995), a specially designed ski glove that assists release (Fairclough and Mintowt-Czyz, 1986), learning to fall correctly using shoulder-trunk rolling in a way that does not expose the shoulder, neck or head to injury

(Morrissey et al, 1987) and strengthening the thumb musculature through pre-season ball squeeze exercises to prevent forced abduction and extension (Morrissey et al, 1987).

Ski poles (or stocks) are carried by both cross country and downhill skiers, but not snowboarders. Skiers use them to push themselves along on the flat or uphill and as part of the skiing turn by 'planting' the pole in the snow.

There are generally three types of handles:

- a) an ordinary handle with the strap connected to the upper part of the handle
- b) a handle with a broad plate on top under which the strap is attached
- c) a handle without a strap and a front bow (often referred to as new grip, pistol or sabre).

There are also three ways of holding the strap (Engvist et al, 1982):

- a) the hand is put up and through the strap from below, grasping both the strap and the handle
- b) the hand is put through the strap from above, grasping the ski pole only
- c) the hand is kept outside the strap.

A variety of ski poles have been designed, and different methods of holding them advocated, to ensure that the released ski pole will fall from the hand during a fall. However, the impact of these measures is not reflected in a reduction in injury rates according to some researchers (Fairclough and Mintowt-Czyz, 1986). This is the rationale behind their design of a webbed ski glove to prevent this injury.

Another significant upper limb injury, particularly in terms of severity, is that of shoulder dislocations. Such injuries accounted for 3.7% of injuries in a 1982 study. Bone fracture or nerve injury can be involved. Restoration of the injured body site to its original position is done as soon as possible, often at the ski resort medical centre. Subsequent immobilisation and rehabilitation are an important part of the management. Limitation of range of movement, recurrent dislocation, neurological sequelae and pain or discomfort under stress can be disabling consequences of the injury (Binet et al, 1985).

Shoulder dislocation was the focus of a retrospective study (Binet et al, 1985) based on 1338 dislocations seen in 11 ski resort consulting rooms in France in the early 1980s. This injury occurred most commonly in adult males (79%) and most commonly on days when the snow was frozen and hard. Eighty-eight percent of dislocations were reduced in the doctor's rooms by simple manipulation without the use of general anaesthesia. Several recommendations were made with regard to the reduction of shoulder injuries. These are presented in the following section.

6.1.2 The effectiveness of ski pole handle or glove design

Thumb injuries, and in particular injuries to the UCL MPJ, are common in skiing and may be chronically disabling if inadequately managed. There is likely to be under reporting of these injuries by skiers and thus an underestimation of the problem in formal injury statistics. The available research consists of: epidemiological studies of injury patterns,

exploration of the association between handle design or the method of holding the ski pole strap and injury rates, an ergonomic evaluation of the mechanism of injury and the contribution of ski pole handle design to this, one prospective study of a new 'sabre' design and a ski glove design. Details of these studies are provided in Appendix 1.

In the studies reviewed, cases were ascertained through injury clinics (Engvist et al, 1982) or skiers at a base lodge (Carr et al, 1981). Generally they used a sample of the general skiing population as controls. In one prospective study (Hauser, 1989), skiers were sent ski poles with a 'new' grip design to use during the season. Participants were skiers who responded to local media/press releases. This study involved a randomly selected group of 160 skiers from all responders and sent them sent ski poles with a new type of bowed grip (Hauser, 1989). A lower percentage of thumb injuries amongst the skiers using these poles (3%), compared to a control group of skiers using normal ski poles was found (4%). Although the percentage is lower, no test of statistical significance was reported in relation to this difference. This makes conclusions about the effectiveness of the special bowed ski pole grip in reducing injuries less definitive. Another limitation of the study was that there was no mention of exposure-related factors in injury causation.

An analysis of three types of ski pole handles, three methods of grip and a combination of these, found no statistical association with injury when the method of grip alone was considered or when the various combinations of handle and grip were compared (Engvist et al, 1982). When the type of ski pole handle was considered, those with a broad plate on top had a higher frequency of injuries than expected. No single explanation was offered for this. It is possible that this design may help stop the pole slipping out of a skier's hand, an advantage at most times other than falling. This design of handle may be accepted or manufactured because it is supposed to reduce the risk of impalement or perforation injuries from falling on to the pole. No specific evidence for this was cited (Ekeland and Nordsletten, 1994). This is a very rare but more serious injury, which would need to be considered in recommendations relating to handle design.

If discarding of the pole is important in injury causation, it would be expected that the position of the strap in relation to the hand would make a difference. However this does not seem to be the case (Engvist, 1982). Based on a review of recordings of falls during World Cup races, it was noted, that these racers retained their ski poles in their hand throughout a fall (although it was not stated whether they actually wore straps). Today's racers all use the straps on their poles (Carey, 1996). It may be a natural reflex to retain one's grip on the pole during a fall and the strap may not influence this. It was not considered justified to promote a handle design that prevented opening of the hand in a fall, as this may lead to more serious injuries. Only small numbers of skiers in both the sample and control groups used the new 'sabre' handle design. It may therefore be premature to discount the potential value of this design.

The report of a survey of base lodge skiers (Carr et al, 1981) was unclear about a number of factors including the population exposed to risk. Of the 408 skiers interviewed, 329 skiers (81%) had straps on their poles. The proportions of skiers sustaining thumb injuries using the various grip techniques were: outside straps (5%); straight through (21%); up, through and down (25%); 'new grips' (pistol, sabre and pullout grips) (27%). Firm conclusions would be difficult to draw from this study given its design and reporting of results.

A study of the ergonomics of ski pole handle design had relatively few cases in some categories that were used for the comparison of injury mechanisms and the contribution of

handle design. This made it difficult to be sure of their conclusions, although the ergonomic arguments seemed sound and reasonable (Ledoux et al, 1989). The use of straps was accorded more importance than in other investigations. The authors were optimistic that the injury rate could be reduced with better design and recommended further research into the removal of straps, placement of safety clips in a proper position, changing of the thumb position to reduce its opposition and allow its participation in pole planting, and freeing the hand's radial edge to it to be freely ejected during falls (Ledoux et al, 1989).

The feasibility of altering a reflex action in the difficult positions in which skiers often find themselves during a fall has not been examined further. A handle designed to retain the pole firmly in the hand, without the reflex opening of the hand or abduction of the thumb, may in turn put the skier at greater risk of other more serious hand injuries.

No type of ski pole in general use today eliminates the risk of injury. Innovations in ski pole handle design have not been associated with a decrease in thumb injury rates (Fairclough and Mintowt-Czyz, 1986; Ledoux et al, 1989). When trying to design a new type of ski pole handle to reduce the risk of thumb injuries, the risk of exposure to other types of injuries must be considered (Engvist et al, 1982). Furthermore, skiers may not wish to ski without handle straps, as to lose the ski pole during a fall may mean a climb back up the hill to recover it.

A ski glove designed to eject the ski pole on falling is an interesting concept (Fairclough and Mintowt-Czyz, 1986). To be effective it would have to be worn without the skier's hand being retained by straps on the pole. The appearance (as schematically illustrated in the article) may deter consumers, but this could possibly be refined. Formal testing of the glove was not reported.

Appropriate examination and management of thumb injuries are important. They can prevent further damage during the examination and are also useful for detecting injuries that require more extensive treatment or specialist referral. Delayed healing or chronic disability can result from inadequate management, and is painful and disabling with loss of hand function and contains the risk of post traumatic arthritis. Taping of the thumb may be helpful for preventing further injury in some sports (eg those involving ball handling). It cannot, however, effectively prevent forced radial deviation, a feature of many skiing injuries (Fricker and Hintermann, 1995).

Less controversial in the design of ski poles is the belief that the sharp end should not have a single point but that it should be cratered, serrated or multi-tipped (Johnson, 1992).

In relation to the prevention of shoulder injuries, French researchers considered that certain preventive measures were relevant at different stages of the injury chain (Binet et al, 1985). In the pre-event stage, such countermeasures include: good physical condition of the skier, instruction on how to fall (given in ski lessons), a realistic appraisal of skiers' abilities so they do not ski on slopes that are too difficult, and good slope preparation. After the event, coordinated and rapid action by rescue services to facilitate reduction of the dislocation as soon as possible and correct immobilisation for the transport by ski patrollers reduces the tension within the patient. It also enables an easier reduction of the injury. These researchers also consider that immobilisation which is more likely to be tolerated by patients, and early and effective rehabilitation, are important and necessary and will hopefully reduce the occurrence of sequelae (Binet et al, 1985).

6.1.3 Summary

Table 5 summarises the type of evidence for the type of ski pole handle design, method of holding and the ski glove design. Four studies provided evaluations of ski pole handle design and one described ski glove design. Of the studies evaluating ski pole handle design, all provided data-based evidence and two provided a detailed examination of equipment design. None of these studies provided a controlled evaluation of these countermeasures.

Table 5 Summary of the type of evidence for ski pole handle design method of holding and ski glove design.

(Each • in the table below represents a different study)

| Countermeasure | Anecdotal or informed opinion | Laboratory-based or equipment design | Data-based (uncontrolled) |
|--|-------------------------------|--------------------------------------|---------------------------|
| Ski pole handle design and method of holding | • | •• | •••• |
| Ski glove design | • | • | • |

On the basis of these studies, the weight of evidence suggesting that any particular handle design or method of holding the strap would have a major influence on the likelihood of injury is weak. Similarly, there is not strong evidence for a significant contribution to injury prevention if all skiers were to use a certain design of ski pole handle or hold their ski poles in a particular way. There were, however, methodological problems with some of the studies and the results were not always clearly presented.

Innovation in design or biomechanical testing and evaluation in relation to this countermeasure does not appear to have been developed to the same extent or to have received as much attention as other countermeasures such as the functional unit of the ski/binding/brake/boot system. This suggests that there is still scope for further development and improvement.

Newer types of handle design may have the potential to result in fewer thumb injuries. However, their evaluation in controlled trials or their use by skiers in the epidemiological studies reviewed here has not been sufficient to provide clear evidence of their potential for injury prevention. The ergonomic study by Ledoux et al (1989) was more optimistic about the potential for reduction of injury. It gave practical suggestions for discontinuation of the use of ski straps altogether (for all but competitive skiers) and improvements in handle design.

The ski glove designed to eject the ski pole from the skier's hand during a fall, was an innovative approach to the problem of thumb injuries, but has yet to be evaluated. There has also been no formal evaluation of improved falling techniques or pre-season exercises for strengthening thumb musculature.

6.1.4 Recommendations for further research, development and implementation

- Further detailed research into the mechanisms of thumb injuries is required to target further appropriate countermeasure development. This could be achieved by conducting interviews with skiers with injured thumbs, to determine the actual sequence of events that led to their injury.
- Further epidemiological and ergonomic research into the design of ski pole handles and ski straps is needed.
- Further biomechanical and developmental research into the design of ski gloves is also required.
- Controlled epidemiological evaluations of both ski pole handles and ski glove designs in the field are required.
- An assessment of correct falling techniques and consideration of what is taught by ski schools in relation to these should be made.
- There should be continued support for a high standard of ski patrol services to provide a rapid response and safe transport of injured skiers.
- Specific advice, or training, for doctors in and around ski field areas, about the examination, management and rehabilitation of thumb and shoulder injuries needs to be developed and promoted.

6.2 SKI BINDINGS, ANTI FRICTION PADS, APPROPRIATE BINDING RELEASE, PROFESSIONAL ADJUSTMENT OF SKI BINDINGS AND SKI BRAKES

6.2.1 Background

Knee injuries are the most common site of injury, accounting for between 20 and 32% of all injuries (Johnson et al, 1979; Shealy and Miller, 1991; Coolahan et al, 1994). In a study in the 1970s in the US, lower extremity injuries accounted for 58% of all skiing injuries, and 80% were classified as lower extremity equipment-related injuries (Gillette, 1980).

With the changes in boot design since the mid-1970s toward higher and more rigid boots, ankle injuries have become less frequent. Knee injuries are now the most common site of injury overall. Inadequate release of ski bindings has been implicated in lower limb injuries. The severity of lower limb injuries varies from ligament strains to ligament ruptures and bone fractures (Johnson et al, 1979; McConkey, 1986; Feagin et al, 1987; Sterett and Krisoff, 1994; Aune et al, 1995; Speer et al, 1995; Johnson, 1995).

Injuries to the medial collateral ligament (MCL), anterior cruciate ligament (ACL) or medial meniscus of the knee are the most common of the more serious injuries. These injuries may need surgical repair and can have serious or longstanding consequences in terms of joint function and stability (McConkey, 1986; Duncan et al, 1995; Johnson et al, 1979; Speer et al, 1995; Aune et al, 1995; Johnson, 1995; Feagin et al, 1987).

Mechanisms of ACL rupture include ‘the phantom foot mechanism’ which is a sudden internal rotation of the hyperflexed knee as the inside edge of the ski is weighted in a curving turn. Other mechanisms are a boot induced anterior draw, a forceful quadriceps contraction or a knee hyperflexion (Ekeland and Nordsletten, 1994).

In alpine or downhill skiing, the ski release binding is the mechanism that attaches the boot to the ski. The heel is held down in a fixed position by the bindings unless the bindings are released. Forces are transmitted through the lower limb and ski boot to the binding mechanism or vice versa. The ski binding is mechanical in nature and consists of a spring actuated toe and heel piece which respond to torsional and upward forces, respectively. The release decisions are determined by spring tensions in the pieces that are adjustable. Ideally, ski bindings should be able to perform two functions: retention and release. Ski bindings should release in response to transmitted forces in time to prevent injury to the skier, but not 'prematurely'.

Binding release performance may be influenced by factors other than adequate and professional adjustment, such as icing of bindings in extreme weather conditions and the condition of the ski boot sole. Boot soles made of material that is easily scratched results in high levels of friction between the ski and the boot and this may inhibit binding release. A number of other devices that may influence the functioning of bindings and the safety of skiing have been developed. Anti-friction pads attached to the skis under the sole of the boot are designed to reduce friction between the ski and the boot during binding release (Johnson, 1995). Ski-brakes (or ski-stoppers) are devices attached to the ski that should open on release of the binding. They act by slowing and stopping the dangerous movement of a ski down the slope thereby reducing the possibility of the collision of a run-away ski with other skiers. Their use is mandatory in Australia. Cross-country skiers using lifts are required to use a safety strap to attach the ski to their boot. Before the development and introduction of ski-stoppers, lacerations and other 'egg-beater' injuries were associated with falling skiers tumbling down the slopes with their skis attached.

Binding characteristics provide better protection for the ankle than knee for several reasons (Johnson, 1995):

- forces at the boot/ski interface are translated up the shaft of the leg to the knee
- upward release force present at the heel has only a moderate correlation with actual bending at the knee
- the binding only senses those forces near the ankle, thereby only providing indirect protection to the knee.

Due to the lever action of the skis, differential acceleration can occur when the body is moving forward relative to the skis. This is associated with characteristic hyperextension/torsion injury mechanisms. Differential acceleration can also occur when a skier is moving backward relative to the skis (Johnson, 1995).

Inadequate binding release has also been implicated in femoral fractures in younger, skeletally immature, 3-18 year olds. These skiers can sustain indirect, torsional injuries to the femoral shaft under conditions such as fast skiing or catching a skise force and the tibial plateau width (Feagin et al, 1987) and ISO standards are set by a weight method (Delouche, 1987). The bindings of the skier are adjusted individually to a given release force or torque that is suitable for that skier. The adjustment is checked by actually measuring that force or torque with a testing device. In practice, adjustment of the fit to the required DIN settings may not be widely undertaken because the retailing and hiring outlets may not have the necessary devices (Carey, 1996)

The forces transmitted through the bindings during skiing can be large, and there is unlikely to be a binding that will respond correctly in all potential release situations. Equipment for skiing, in particular the functional unit of the ski/binding/brake/boot system,

has improved through research, standardisation and testing over the last 15 years. Ski bindings are probably the most researched skiing injury countermeasure in terms of biomechanical design and testing. Epidemiological studies have been used to examine the effectiveness of pre-skiing professional testing of the binding adjustment (including the use of testing devices) for preventing injuries and modifying risk.

It has been proposed, however, that efforts directed towards choosing the most appropriate equipment for individual skiers, better mounting of the binding, and reliable individual binding adjustment may be of greater importance in the reduction of injury (Nagel and Reuleaux, 1985).

Bindings are often not checked on a regular basis by people who have had their skis for a substantial period of time. Beginners generally have the cheapest and lowest quality bindings without fine tuning adjustments and release in all directions. It should be a requirement that ALL skiers have good bindings, irrespective of their level of expertise (Carey, 1996).

6.2.2 The effectiveness of ski bindings, anti friction pads, appropriate binding release, professional adjustment of ski bindings and ski stoppers

The articles reviewed here are related to the study of the biomechanics of ski bindings and their release in response to various loads and loading patterns. Other studies have looked at the contribution of bindings and their release to lower extremity equipment-related injuries, the effect of various methods of binding adjustment, and the determinants of skiers' behaviour in getting their bindings adjusted professionally. Another study reviewed computer controlled release binding prototypes constructed for biomechanical testing purposes, and were not commercially available bindings. Full details of the studies reviewed here are given in Appendix 3.

Many of the studies reviewed in this section are over 10 years old since little current information or recent studies could be identified in this review. The relevance of these studies to today's equipment may therefore be questionable, given the changes in ski equipment over the past 10 years. Nevertheless, the studies are summarised here for completeness. Although, for example, there have been considerable technological advances in both alpine and cross-country skiing since its publication, the 1970 report by Outwater (1970) provides a good introduction to the principles of coefficients of friction in skiing.

The influence of professional adjustment of bindings on the risk of injury has been considered by several researchers. One survey (Rosen et al, 1982) set out to include both injured skiers presenting to a medical centre and uninjured skiers randomly selected from those approaching the base lodge. Behavioural determinants of the failure of individuals to adjust release bindings were compared in the two groups. All skiers were skiing on their own equipment. Unfortunately, the analysis did not consider these groups separately, and the fact that they were injured may have influenced their responses. The survey determined whether or not skiers had obtained a binding adjustment in the last 6 months (either professionally or by self). It is not clear from the results or discussion whether the groups of binding adjustment by professional or self are mutually exclusive. Furthermore the denominator population was not clear (Rosen et al, 1982). The results may have been different if the injured and uninjured skiers had been separated in the analysis.

The desired outcome of "Have your bindings adjusted in a ski shop with the aid of a test device" was investigated in another study (Damoiseaux et al, 1991). This was assessed by

comparing mean scores for variables such as adjustment behaviour, attention and comprehension in two groups. The percentages of positive intention were also compared. The linking of injuries and adjustment of bindings was reported in broad terms only. The numbers may have been too small to do otherwise but the reporting of this is not detailed enough. It was intended that this survey would serve as the prototype for a national campaign to reduce ski injuries among Dutch skiers. However, the researchers rightly query whether this survey constitutes sufficient basis for a national mass media campaign. They acknowledge that it is difficult to prove that a health education intervention can minimise the number of injuries in that an occasional leaflet/cassette is unlikely to produce permanent behavioural change. The study population was considered too small to detect a reduction in ski injuries and there was no baseline level for comparison.

A study conducted by Bouter et al (1989b) was the most rigorous in terms of its analysis, adjustment for confounding factors and consideration of biases and validity. There was probably some selection bias with respect to age and gender in the selection of controls but this was adjusted for in the analysis. The researchers' conclusion that "it is doubtful whether an optimally adjusted binding will always release in time to prevent a lower extremity injury.... and there still seems to be room for further improvement in the design of the ski binding" seems to summarise the situation well. They also suggest an explanation for their finding of no association between factors relevant to binding adjustment and injury risk. Perhaps the proxy measures of binding adjustment were too insensitive, or too biased, to detect the risk of injury associated with badly adjusted bindings. The researchers recommended that direct measurement of bindings in observational studies be a critical part of future studies.

Only one prospective cohort study (Hauser, 1989) was identified in this review that used a control population for comparison. The findings of this prospective study (Hauser, 1989) were that a large proportion of bindings in adult skiers was badly adjusted. It was also found that the rate of lower extremity equipment related injuries in a group with properly adjusted bindings was 3.5 times lower than in a control group without such adjustment. The researchers concluded that lower extremity equipment related injuries decreased, as did some other injuries, with properly adjusted bindings. A considerable proportion (50%) of bindings were badly adjusted before being optimally adjusted by the research team. Some of the lower extremity equipment related injuries were due to inadvertent release, but the rate of inadvertent release was lower in the control group. Unfortunately, this study lacks detail on the injuries that were reported, or their severity, across the two groups (those who had their bindings professionally adjusted as part of the study and those who did not). One needs to accept the authors' conclusions on this since the results are not detailed in the article.

A strong point of a Vermont study of knee injuries (Johnson et al, 1979) was that it was comprehensive in its endeavours to assess both the skiing ability and binding function of the skiers involved. Where possible, an assessment of bindings by a technician was undertaken.

A number of studies confirm the magnitude of forces transmitted through the lower limb during skiing and the difficulties binding systems have in responding to prevent injury. These studies emphasised the need for multi-directional release sensitivities in bindings. Some of these were studies from the early to mid 1980s and the technology may have been superseded. Others related to prototypes rather than commercially available bindings in use by skiers.

A preliminary model of a microcomputer controlled ski binding that was at the stage of being tested both in the laboratory and in the field was described by MacGregor et al (1985). An actively controlled binding mechanism that has knowledge of both deformations of the lower limb musculoskeletal system and its critical limits, and which can release appropriately in response to various combinations of forces, is a promising design concept. The researchers acknowledged that there was more work to be done to achieve a mechanism meeting these criteria (MacGregor et al, 1985).

A further study used quasistatic (ie almost static) testing for the prediction of dynamic properties of a binding. The authors of this study commented that "after a fall or a collision there is rapid deceleration and the events in the binding quickly change from dynamic to semi static" (Lindsjo et al, 1983). This allows some conclusions to be drawn about the function of different bindings in skiing accidents. One of the functions of a binding is to release at potentially injurious force levels while the skier is still moving, often at rapid speeds, and not just after a fall. Quasistatic testing has also been used in some other studies of this type.

Two studies have concentrated on children's bindings (Ungerholm et al, 1984; Ungerholm and Gustavsson, 1985). These found that many of the release bindings used by children were of poor quality and were poorly adjusted. These studies are summarised in Appendix 4. Significant differences were often detected between the release force of the binding and that recommended in international standards, or between the setting on the binding scale and that recorded when a testing device was used. These were noted to be more marked in an injured group of children.

In one of these studies (Ungerholm et al, 1984), the researchers recognised that the quality of ski boot worn by a child may affect the release of the binding. This may be a confounding factor between the injured and control groups. They acknowledged that inclusion of an assessment of the weighted boot in the ski would have added to the completeness of the methodology. The conclusion was that there is room for major improvements to the mechanical functioning of children's bindings, including the setting standard on the binding itself, the testing methods for adjustment of the bindings, and the frequency of this adjustment. The IAS reference system was recommended (Ungerholm et al, 1984).

In another survey of injured children and binding adjustment (Ungerholm and Gustavsson, 1985) the 'who' and 'where' of binding adjustment did not seem to make a difference. In spite of this, for an accurate adjustment of bindings the setting of children's bindings by the scale on the binding itself was not reliable, nor was self testing. The researchers recommended that heel mechanisms be set according to the standard scale, whereas the toe mechanism should be set as loosely as possible without causing a release during normal skiing, until more reliable bindings and reference systems become available. These researchers also recommended that testing should be done using a testing device (Ungerholm and Gustavsson, 1985).

A study of the binding adjustment of ski racers also found faults in the bindings (Ekeland and Lund, 1987). It also found that the tested release value deviated from the binding scale, although to a lesser degree to those reported in children's bindings. This was more common in bindings that were older, those that were at the lower end of the model range of a particular binding manufacturer, those that were not actuated in the preceding week and those of recreational, as distinct from racing, skiers (Ekeland and Lund, 1987).

Whether the answer to improved binding control, lies in better technical design or better binding adjustment is not answered fully for all age groups. It is probably a combination of both. Improved binding design is more the realm of researchers and binding manufacturers. However, regular and professional adjustment of bindings using a test device is a preventive measure that consumers can promote and demand the standardisation of.

Testing with a mechanical device, by an expert, provides the opportunity for an actual check and adjustment of all components of the binding system. Advice can then be provided if the bindings are faulty or cannot be adjusted. Test devices are considered essential for the detection and correction of incorrect adjustment or functional disturbances of bindings.

Adjustment solely on the basis of binding setting scales is not advised. The tolerances of the specific bindings and boot, as well as the influences of wear and tear and the environment (dirt and ageing), can result in deviations from the value indicated on the setting scale (Nagel and Mosch, 1987). Requirements for the accuracy, operation, handling, use, maintenance and calibration of test devices are specified in DIN 32 921 standards (Nagel and Mosch, 1987).

Test devices have the capacity to register input, calculate data and measured release values and produce a printed output. To set bindings according to standard values, personnel of sports shops control the release forces or torques with a test device. Both force- and torque-measuring devices are in use and these different measuring principles have both advantages and disadvantages. A torque-measuring device that is easy to handle is considered the best option (Nagel and Mosch, 1987).

Sports and equipment hire shops and their personnel have responsibility for the selection of the functional unit (ie ski/binding/brake/boot) that is most appropriate for the individual skier and for making the correct adjustments. The DIN 32 923 standard specifies the correct procedure from the sales consultation to the delivery of the functional unit (Nagel and Mosch, 1987).

Equipment associated with the testing devices with data output printers that provide a record for both the ski shop and the skier may assist in fulfilling legal responsibilities. An exact binding adjustment without using test devices is not considered possible (Nagel and Mosch, 1987). Adequate training of personnel in the use of testing devices is obviously important.

The validity of the binding adjustment can be influenced by parameters such as the sole length of the boot, the testing machine and operator variability, and information used in the assessment of the 'correct' adjustment for each skier, such as self-reported weight or self-assessment of skiing ability (Delouche, 1987).

The standards development process has been hailed as having had two important positive effects on the development of safer bindings. These are the development of the standards themselves and the deliberations that took place in their development (Ettliger, 1985). West Germany has made its DIN standards mandatory and companies wishing to trade in their market are therefore required to manufacture equipment that meet them. In a 1985 review of the standards process, these standards have been criticised as relatively weak. They have also been criticised for fostering an attitude of complacency and suppressing the market potential for improved design in boots, ski brakes and bindings. The standards process was also criticised for not having addressed the rate of knee injuries and for not

considering the frictional properties of outer garments which can be a contributing factor when skiers slide and collide into stationary objects (Ettliger, 1985).

Special attention has been drawn to the high frequency of maladjustments in children's bindings. Knowledge of injury thresholds and mechanisms of injury for children is lacking or not as comprehensive as for adults. Attention has also been drawn to the difficulties in assessing the release functions of children's alpine ski bindings (Gundersen, 1987). Several reasons for this have been suggested including:

- the range of deviations allowable in the manufacturing process may be reasonable for adults but not for children
- the DIN norm does not take into account the effect of soft boot materials that are more commonly used in children's than adult boots
- DIN 7881 does not deal with the problem of dirty boot soles
- boot sole lengths, as defined by DIN, and the recommended settings need revision.

In relation to these problems, Gundersen (1987) has recommended:

- a tightening of the tolerance range of children's bindings
- alternative setting scales which take into account the effect of soft boot materials, or the requiring of high quality materials for children's boots
- allowing for the fact that children may be using boots that have been walked in to get to the ski slopes, especially in Scandinavian countries, deciding for in norms for binding settings
- encouraging manufacturers to state alternative settings according to weight, typical shoe size and torque settings, according to ASTM guidelines
- parents and older children should be encouraged to seek professional adjustment of bindings rather than making the adjustments themselves.

The contribution of bad adjustment to injury risk needs to be quantified by further experimental studies. In these studies, the bindings of randomly chosen skiers should be optimally adjusted and a comparison of the rates of injury between these skiers and a control group measured. However, there may be some ethical problems with this, since there is some evidence already that professional adjustment is desirable.

Based on trends and hypotheses generated from three sources (surveillance data on injuries treated at Perisher Valley Medical Centre 1987-92, skiing injuries treated at NSW hospitals 1989-93, and data from the National Injury Surveillance Unit's Injury Surveillance Information System (ISIS) set up at Perisher in 1992), a number of recommendations for injury prevention were made by Coolahan et al (1994):

- redesign of ski bindings and boots
- review of currently used binding adjustment tables (especially for women)
- introduction of mechanical testing for torque and adjustment of bindings
- development of standards for ski equipment
- promote skier's awareness of fitness, weather and fatigue

In the case of elite skiers, several possible solutions to prevent knee injuries have been put forward. These include consideration that predictors such as the relationship of knee extensors and flexors in certain hamstrings:quadriceps (H/Q) ratios may not be as useful as once thought; increased acceptance by athletes and coaches of the protective nature of binding release in response to forces on the injury threshold that may occur prior to a fall; and new binding developments such as an 'educated' binding that senses a combination of upward and lateral forces at the toe and heel, strain on the back of the ski boot, and one or more body position markers such as knee angle (Johnson, 1995).

The burden of lower extremity equipment related injuries has been considered by researchers in Germany (Hauser, 1989). They estimated that of the 80,000 skiing injuries that must be medically treated each year, approximately 30,000 could have been avoided if skiers used currently available equipment that was properly mounted and adjusted. Of these, 20,000 would be lower extremity equipment related injuries and 10,000 to other body regions. The remaining 50,000 relate to skiers' behaviour.

Statistics of the Deutscher Kiverband e. V (DSV) (the German Ski Federation) showed that only 46% of skiers in the Federal Republic of Germany in 1981 used correctly set bindings (Nagel and Reuleaux, 1985). As a result the Technischer Überwachungs-Verein Bayern e. V. (TÜV Bayern) developed a common training program for ski shop personnel in cooperation with the DSV, the Internationaler Arbeitskreis Sicherheit beim Skilauf e. V. (IAS), and the Bayerisches Landesinstitut für Arbeitsschutz (LAS) (Nagel and Reuleaux, 1985).

This program forms the basis of training seminars designed to give ski shop personnel all-round expertise in the safety properties of ski equipment and the correct selection, mounting and setting of the functional unit. It also assesses their competence by means of a multiple choice and practical examinations. If successful, they are issued with a diploma. This helps consumers to choose ski shops that have competent personnel working in them. With the purchase of a functional unit, consumers are also provided with a descriptive setting card for the unit. The authors noted, however, that improvements in the design to help reduce the possibility of error during the assembly, mounting and adjustment of the functional unit in the future should be encouraged (Nagel and Reuleaux, 1985).

6.2.3 Summary

Table 6 summarises the strength of the evidence for ski binding design, and associated factors, as major injury countermeasures. A total of 14 studies was identified in this review. All but one of these studies focussed on equipment design. Six studies reported a data-based evaluation of ski bindings and only one study involved a controlled trial. One study considered skiers' acceptance of an electronically controlled binding system that they carried with them.

Table 6 Summary of the type of evidence for factors associated with ski bindings

(Each • in the table below represents a different study)

| Anecdotal or informed opinion | Laboratory-based or equipment design | Data-based (uncontrolled) | Controlled evaluation | Consumer attitudes |
|-------------------------------|--------------------------------------|---------------------------|-----------------------|--------------------|
| •••••••• | •••••••••• | ••••• | • | • |

The weight of evidence suggests that current bindings do not address sufficiently well the multi-directional release required to reduce the risk of lower limb, and especially knee, injuries and that further technical developments and innovations are required. The standard of bindings and boots also needs to be considered.

Optimal adjustment of bindings using a testing device has been shown to be associated with a reduced risk of lower extremity injury.

The adjustment of bindings that are in use has been shown to be inadequate, especially in the case of children's bindings. Adjustment by the binding scale on the binding itself is not likely to be sufficiently accurate. For an accurate adjustment, use of a testing device by adequately trained personnel is essential. This testing should be standardised and performed regularly. There is also room for improvement in the field of international standards.

6.2.4 Recommendations for further research, development and implementation

- Continued research into, and development of, multi-directional release bindings.
- Ongoing evaluation of current ski binding designs.
- Case control studies to evaluate the methods for, and the effectiveness of the different methods of binding adjustment.
- Australian studies on the adequacy of skiers' binding adjustment in both children and adults.
- Particular attention needs to be given to standards for, and adjustment of, children's boots and bindings.
- Retailers and hiring outlets should obtain and use mechanical testing devices for achieving the required DIN settings.
- Regulations and standards for ski shops and ski hire outlets dealing with the training of personnel and the use of mechanical testing devices should be implemented, where they are not already in place.
- Investigate the role of skier education to improve knowledge about the importance of ski bindings.
- Improved skier education about binding release and adequate adjustment needs to be achieved.
- Various modes of skier education need to be tested to determine which is the most effective approach (eg pamphlets on arrival at the slopes, promotional campaigns on the slopes, etc.)

6.3 SKI BOOTS AND SKIS

6.3.1 Background

Epidemiological trends in skiing injuries were evaluated through a prospective study of 6671 injuries presenting to a Vermont ski clinic between 1972 and 1990. Over this period, injuries below the knee showed the greatest decline while serious knee sprains, usually involving the anterior cruciate ligament (ACL, a major ligament which attaches the femur to the tibia) had shown the largest and most significant increase. There was a significant reduction in ankle injuries (ie, fracture of lateral malleolus, ankle sprain) and lower tibial

fractures and strains (Johnson et al, 1993). This reduction is at least in part due to the advent of stiffer, higher boots in the late 1960s. Other factors such as improved ski construction and grooming of ski slopes have also contributed to this decline.

A particular type of tibial fracture is the 'boot top' fracture. This involves a low transverse fracture of the tibial shaft at the level of the ski boot rim. It usually arises when the forward motion of a skier is abruptly halted and the skier falls forward against the hard rim of the boot (Hoflin and van der Linden, 1976). This can occur when skiers collide with an obstacle at speed or suddenly run into soft snow.

Epidemiological trends in this type of injury reflect the increased popularity of downhill skiing and the use of stiffer, higher boots during the 1960s. They also reflect the introduction, in the late 1960s, of a new technique for 'sitting back' whilst skiing that resulted in a change in the type of boot top fracture (Hoflin and van der Linden, 1976). The injury occurs most commonly in males <20 years. In a survey of 600 patients admitted to a Swedish hospital with tibial shaft fractures, 416 were skiing related. From 1967-1969 the boot top fracture accounted for 25% of all tibial shaft fractures and 37% from 1972 to 1973 (Hoflin and van der Linden, 1976).

The May 1980 IAS 150 specification for adult ski boots states, in its introduction, the technical properties required for the safety of ski boots. The major property is that the boots, together with safety ski bindings, must act as a mechanical element in the transfer of forces. This specification also refers to some boot sole characteristics that correlate with the reduction of lower extremity (and potentially equipment related) injuries (Lyle and Hubbard, 1991).

Ski bindings should release when the boot is subject to force in a forward direction as well as with a rotary stress. They should, ideally, release when the skier is sitting back as well as when they fall back (Hoflin and van der Linden, 1976).

Failure of the boot to act as a load distributing device in transferring the load from the skier to the binding may be a major factor in bending fractures of the tibia. Spiral fractures of the tibia are considered to be a lower leg twisting injury (Johnson et al, 1993). Torsional (or twisting) injuries of the tibia have reduced more than bending fractures. Tibial fractures can require internal fixation or long periods in casts. Delayed or non-union can be a serious complication (Hoflin and van der Linden, 1976).

Ski boot technology has developed over the last 25 years from lace up leather boots to moulded plastic boots. There are a number of different entry and closure styles, boot heights, stiffness characteristics, insulation materials, and styles suitable to all standards of skiers.

There are two main types of ski boots. The rear entry boot is favoured by recreational skiers because it is easy to use and comfortable. However, such boots do have some slack in them. All racers use conventional clip boots and this may explain the observation that ankle injuries in racers are very rare (Carey, 1996).

A further consideration is that the general skiing population may use a lot of old equipment. This may be handed down from other skiers or be equipment that has not been changed for many years by recreational skiers because of the expense. This equipment ages and is often not regularly checked. Alpine racers, on the other hand, change their equipment every few years (Carey, 1996).

The hire equipment from resorts, etc, is often of a higher standard, newer, more often checked and regularly maintained than the equipment of skiers using their own gear. It would be interesting to ascertain whether skiers who use their own equipment are more at risk of injury than those who hire it.

Ski boots provide support for the foot, ankle and lower leg and assist in transmitting forces from the skier to the binding system and vice versa. The stiffness of the boot has also been associated with injury and boot top fractures. Recreational skiers need a boot that allows painless skiing over the full range of forward flexion. Poorly fitting ski boots can cause painful blisters. The construction of ski boots should not allow any localised pressure areas. Boots should also be insulated and keep skiers' feet warm.

There has been very little literature about injuries that occur during telemark skiing (Ekeland, 1995). Telemark skiers, unlike alpine skiers, do not have a fixed heel and have lower and softer boots. It would be interesting to compare the leg injuries rates among telemark skiers with that of both alpine and cross-country skiers.

6.3.2 The effectiveness of ski boots

Many theoretical or biomechanical studies have been done on ski bindings but few on the effectiveness of ski boots for preventing injury. The studies summarised in Appendix 5 relate to case studies of boot top fractures, investigations of boot stiffness and boot shaft characteristics, and analysis of the pain threshold of the lower leg and the effect of temperature on this.

One study of ski boot stiffness in relation to boot top fractures gives no clear idea of what the optimal boot might look like in practice. Furthermore, it did not address the potential influence of boot design on the rate of other injuries (eg to the knee) (Lyle and Hubbard, 1991).

Individual differences in pain threshold mean that definitive recommendations cannot be made. The important differences between males and females in this respect, and the need to recognise these differences in designing boots and boot specifications, is recognised. An advantage of a more flexible boot is that increased hamstring activity may protect the ACL if a skier should fall backwards (Bauman and Walkhoff, 1993). However, this contention has not been formally evaluated.

A wide variety of boot characteristics such as fit, stiffness, length, friction coefficient, wear and cleanliness may influence the ability of the binding to release during a fall. Boots need to fit well around the foot and lower leg or the forces will not be transmitted to the binding release mechanism (Johnson, 1992). A skier may partially unbuckle uncomfortable boots while still skiing, thus reducing control and transmission of forces to the release mechanism, or leave the ankle at risk of twisting injuries (Johnson, 1992).

Boots and skis should be selected according to the ability of the skier (Ekeland and Nordsletten, 1994). The boots should be well insulated to keep the feet warm and well padded to prevent compression (Ekeland and Nordsletten, 1994).

Schaff et al (1991) suggest the following requirements for ski boots:

- they should be classified according to the gender of the wearer because females have a significantly lower pain threshold that may lead to a restriction of movement and a reluctance to forward flexion in a stiff boot designed primarily for males

- they should provide temperature isolation so that the feet are kept warm. This is important for both comfort and safety as constant sensation feedback, necessary for accurate skiing is only granted at constant temperature
- the force along the lower leg should be distributed homogeneously over a large area to avoid pain at low pressure
- the area of most pressure should not be distributed along the tibialis anterior tendon because even low pressure over time may lead to a tenosynovitis.

Ski equipment used by children may be of a poorer fit or standard and the bindings less sophisticated (Ungerholm et al, 1984; Ungerholm and Gustavsson, 1985; Gundersen, 1987; Sherry et al, 1987; Giddings et al, 1993). This may account for a higher incidence of tibial fractures in children compared to adult skiers (Garrick and Requa, 1979; Blitzer et al, 1984; Sherry et al, 1987; Ekeland et al, 1993; Giddings et al, 1993).

6.3.3 Summary

Four studies have looked specifically at the role of ski boot design as a measure to prevent ski injuries. Each of these studies involved biomechanical/equipment testing and provided some further informed opinion on the role of boot design. Unfortunately, there has been little formal evaluation of boot design as a countermeasure in injury prevention and how this relates to boot stiffness characteristics and pain threshold. The available evidence is based more on informed opinion, than formal trials or tests. Boot characteristics, such as individualised fit and comfort, temperature isolation, and lack of pressure areas are obviously important and, logically, can be expected to help prevent thermal or mechanical injury. The role of ski boot design in the transmission of forces and appropriate binding release is less well investigated, as is the role of the boot in prevention of ligamentous knee injuries. Boot characteristics and choice need to be considered in association with the ski/binding unit as has been recommended. The standard of children's boots and equipment in general needs attention.

6.3.4 Recommendations for research, development and implementation

- Further research into the characteristics of boot design that are relevant to comfort and reduction of lower leg and knee injury.
- Formal evaluations of boot design as a countermeasure in the reduction of injury.
- There needs to be more attention given to the design and standard of children's ski boots.
- Future boot specifications should address differences between men and women (and children).
- The role of consumer education about ski boot design and function in relation to injury prevention needs investigation.
- Data about lower extremity injuries in telemark skiers should be collected and compared with that of alpine and cross-country skiers.
- An epidemiological study to determine any associations between 'hired' versus 'owned' skiing equipment and injury risk needs to be undertaken.

6.4 SKIER ATTITUDES, KNOWLEDGE AND BEHAVIOUR AND SKIER EDUCATION REGARDING PROFESSIONAL ADJUSTMENT OF BINDINGS AND OTHER RISK FACTORS

6.4.1 Background

Two studies that have evaluated educational campaigns (Rosen et al, 1982; Damoiseaux et al, 1991) were considered also in the section on ski bindings and binding adjustment. Whether skiers adjusted their bindings or not was related to a combination of factors and the motivating or deciding factors were not found to be identified. Some indications of the timing, approach and means of delivery of a message related to binding adjustments were gained from a controlled study. The researchers, however, did not consider this sufficient for the basis of a national campaign (Damoiseaux et al, 1991).

A retrospective epidemiological study of Dutch skiers examined behavioural risk factors in relation to injury rates and reported on the etiologic fractions of these factors (Bouter and Knipschild, 1991). Etiologic fractions give a measure of the proportion by which the injury incidence rate amongst people exposed to a particular behavioural risk factor would be reduced, if the exposure was eliminated. The researchers concluded better evidence existed for increased injury risk in relation to inadequate adjustment of bindings, failure of beginners to take ski lessons, and an underestimation of actual risks involved in skiing by skiers, than for ski lessons, a pre-season course of ski gymnastics or level of daily alcohol consumption.

A general review of the role of planned health education for skiers covered examples of planning and evaluation in health education, the associated pitfalls, behaviour determinants, interventions and health promotion (Kok and Bouter, 1990). With few formal or evaluated trials, gaps in current knowledge exist in relation to specific determinants of desirable or undesirable behaviour and skiing injuries. Epidemiological studies followed by research on behaviour determinants were recommended (Kok and Bouter, 1990).

A Catalan television station ran a three minute segment on topics related to the causes of skiing injuries and their prevention. It was included in a 20 minute evening weekly program about winter sports during the 1985-7 winter seasons, and presented by a doctor from a Barcelona hospital orthopaedic department (Figeuras, 1989). The broad range of topics presented included the skiing environment (type of snow, type of slope, signalling and layout of slopes, weather conditions), skiing equipment (skis, bindings, ski poles, outfits, sunglasses) and the skier (physical fitness, experience and technical level, fatigue, age, diet). Advice on four basic principles for the prevention of injuries was repeated at the end of each program. These were:

- adjustment and control of the safety bindings
- improvement of technical level
- skiing according to ability level
- skiing on well prepared slopes.

The effectiveness of the programs was not formally evaluated, but during the weekly series of programs the audience progressively increased (Figeuras, 1989). However, this increase may have been unrelated to the injury message itself.

“Snowsafe” is a Victorian initiative (Victorian Ski Association, 1995). It is disseminated as a comprehensive safety booklet for visitors to Victoria's alpine areas and resorts and is published by the Victorian Ski Association Inc. The large number of organisations acknowledged as contributors by the Alpine Safety Committee in the most recent edition, is a reflection of the initiative and depth of organisations involved in skiing safety in Victoria. With practical information it addresses safety issues to assist in making trips to the alpine region more enjoyable for skiers, resort cross-country skiers and ski tourers, bushwalkers and more general visitors.

“Snowsafe” has not been formally evaluated but, anecdotally, it has been reported as being a life saving resource by skiers lost in the snow. Snowsafe is also available on video, and is compulsory viewing for all schools planning trips to the snow. A pocket-size waterproof bright orange card, the "Snowsafe Emergency Guide", is designed to be carried at all times. It has information relevant to survival in adverse conditions, and can be used as a marker for rescuers.

6.4.2 Summary

Technological developments in ski equipment, standardisation of professional testing of ski bindings, and optimal adjustment of ski bindings have been recommendations earlier in this review. Skiers' attitudes, knowledge and behaviours regarding injury prevention are another important aspect of implementing countermeasures. Thus an understanding of these factors, including any barriers, is important in assisting the promotion of preventive measures. Unfortunately, methods for achieving this have not been extensively researched.

Appendix 6 summarises a study which investigated the influence of skier behaviour on injury outcomes. Appendix 7 summarises the studies that have evaluated skier education campaigns.

6.4.3 Recommendations for research, development and implementation

- A study of Australian skiers' attitudes, knowledge and behaviours in relation to risk factors associated with skiing injuries is required.
- The results of this study should be used as a basis for educational and injury prevention programs, and promotion of injury prevention countermeasures among Australian skiers.
- Research into different strategies or modes of educational delivery should be explored.
- A review of health promotion programs and adoption of injury prevention countermeasures should be conducted. This should include the experiences of other sports that may be relevant to skiing.

6.5 PRE-SEASON CONDITIONING

6.5.1 Background

Skiing is a physically demanding sport. The average recreational skier in Australia may ski for only a limited period each year, whether it is for a week or two, occasional weekends or day trips. Skiers like to make the most of their time on the slopes once there, but face the risk of becoming fatigued. Skiing all day, every day, without physical preparation can put skiers at risk of injury. The muscle and joint soreness and fatigue at the end of a day's skiing can reduce a skier's enjoyment of the sport.

Injuries tend to occur at particular times of the day (ie late morning between 11 and 12 am and 2 and 3 pm) with most injuries occurring in the afternoon (Sterett and Krisoff, 1994). A similar pattern has been reported by Westlin (1976). The pattern of injury in alpine skiing is similar to that for cross-country skiing but with the peaks occurring slightly later than those of cross-country skiing (Westlin, 1976). The fatigue that develops before lunch and toward the end of the day can have a detrimental effect on coordination and reaction time. Australian conditions often mean icy runs first thing in the morning and a late afternoon heavy 'soupy' snow, both of which are difficult conditions for skiing (Australian Physiotherapy Association, 1989).

Skiing requires muscle endurance, strength, flexibility and cardiopulmonary fitness. Whilst highly trained athletes (racers) and experienced skiers have injuries, the recreational skier with low skills and inadequate physical preparation may be at greater risk.

The Australian Physiotherapy Association's (APA) "Get Fit to Ski" program aims to improve four major areas of fitness for skiing: strength, flexibility, endurance, and postural awareness/proprioception. Classes run for 1 hour, twice per week from late May to July. Participants are encouraged to supplement this with swimming, running or bike riding 2 or 3 times per week. The program coordinators acknowledge that timing can present a problem if the ski season starts late.

6.5.2 The effectiveness of pre season conditioning

An evaluation of the APA's "Get Fit to Ski" program sought the responses of skiers to a questionnaire. The results indicated positive perceived benefits from participants, with 96% indicating their intention to attend classes in the following season. Unfortunately, with respect to injury prevention, there was no baseline for comparison. Nevertheless, 75% of the survey respondents completed the season without injury. If the remaining 25% of skiers sustained an injury, this percentage is high. This is not, however, clear from the report (Australian Physiotherapy Association, 1989).

A study of Dutch skiers, which investigated ability and risk factors in downhill skiing reported no beneficial effect of preseason ski gymnastics or a good physical condition. This study had some difficulty in validating the results because of the variability of the data and the self-reported nature of the response. The authors acknowledged that their results needed to be interpreted with caution (Bouter et al, 1989a).

Similar difficulties in interpretation were encountered in an analysis of behavioural risk factors for skiing, which found no protective effect from pre-season ski gymnastic preparation (Bouter and Knipschild, 1991). In this study it was not explicitly stated whether other factors such as age or existing general level of fitness were controlled for in the calculation of risk.

The requirements of a musculoskeletal conditioning program to prepare for skiing was described by Morrissey (1987). This was based on a comprehensive literature review and informed opinion of the anaerobic and aerobic energy demands, biomechanics and physiology of human movement and injury, muscles used and type of contraction for both alpine and cross-country skiing (Morrissey, 1987). Separate programs were suggested for improving performance in alpine and cross-country programs. These involved training at least 2 days/week during the off-season, and 3 days/week during the ski season, with, ideally, a strengthening or endurance program on alternate days for 6 days/week.

Whether recreational skiers are likely to commit themselves to such a rigorous and sustained program is questionable. The authors acknowledge that research and evaluation was needed to determine the effectiveness of conditioning programs for preventing musculoskeletal injuries. They were not aware of any studies that had addressed this (Morrissey, 1987).

Approaches to the study of the effectiveness of preseason conditioning in the reduction of skiing injury face methodological difficulties, particularly with respect to retrospective self-assessment/reporting and validity. It is also possible that the general recreational skiing population may not accept the requirements of a rigorous training program that may have a more substantial and measurable impact on the reduction of injury rates. Expert and informed opinion is in favour of pre-season conditioning, and such conditioning should not be discouraged, but its effectiveness in preventing injury has not been formally evaluated.

6.5.3 Summary

Two studies have investigated the effect of physical conditioning on injury outcome. These studies, both data-based, are summarised in Appendix 8.

6.5.4 Recommendations for research, development and implementation

- Additional research into the effectiveness of conditioning programs on the prevention of skiing injuries is required.
- A more rigorous evaluation of the impact and health outcomes of the Australian Physiotherapy Association's "Get Fit to Ski with Physiotherapy" program should be undertaken.

6.6 SKI LESSONS

6.6.1 Background

Ski lessons are available at most Australian resorts, and certainly at the major ones. Ski lessons can be undertaken in a variety of alpine sports (downhill, cross country skiing and snowboarding) and at all levels. They are taught by instructors accredited by the relevant professional body. One of these bodies is the Australian Professional Ski Instructors Association (APSI) which is responsible for the training and qualification of alpine and snowboard instructors.

Ski school lessons (from a trained professional) are recommended in the "SnowSafe" safety booklet (Victorian Ski Association, 1995) on the basis that:

- statistics prove that more experienced skiers have less accidents, and the best way to gain that experience is to take lessons
- training progresses from the level the skier has already attained
- general enjoyment of the sport is often related to the ability to handle different conditions and terrains and lessons assist in broadening a skiers' capabilities
- lessons provide fun and social contact
- skiers can inform instructors of what aspects of skiing they would like to improve
- instructors can direct participants to the most suitable ski runs after the lesson.

A number of epidemiological studies of injuries among skiers have considered the association of ability, and sometimes a history of having taken ski lessons, with injury rates. Difficulties in interpreting the results, and weighing up the evidence, lie in the reliability of self-reported of ability and a lack of consistency (or definition thereof) in the categories used to report ability and the history of ski lessons.

A study conducted in the 1970s reported an injury ratio of up to 5:1 for beginners compared to expert skiers (Spademan, 1978). A prospective study (Johnson et al, 1993) of injuries in Vermont between 1972 and 1990 found the ratio of injured:uninjured skiers in the beginner/novice category was about 4:1. The injured:uninjured ratio for the advanced/expert category was 1:2. No evidence was provided as to whether members of either group had or hadn't taken lessons.

A Dutch study found a higher injury risk in beginners with no overall effect of ski lessons in reduction of injury risk (Bouter and Knipschild, 1991). Among skiers with 1-2 years experience, ski lessons seemed to have a protective effect (Bouter et al, 1989a). These researchers considered that these results may not be generalisable to other countries for several reasons. These included a greater basic level of experience in other countries and a different rate of participation in ski lessons (Bouter and Knipschild, 1991).

In children, the risk of injury was considered to be up to 9 times the average, whereas intermediate skiers were under represented in the injured skiers (Ekeland et al, 1993). Skiers with less skill or experience were found to have a higher incidence of injuries compared to more experienced skiers or a control population (Garrick and Requa, 1979; Blitzer et al, 1984). A New Zealand study also found beginners, and those who had skied fewer than 3 days that season and had not had lessons to have higher injury rates. Australian studies of injury in children report that more children than adults are beginners and ability is considered to be a risk factor (Sherry et al, 1987; Giddings et al, 1993).

A retrospective case review of fractures of the femur found that the majority occurred in advanced or expert skiers (30%) and intermediate (48%) skiers rather than novice skiers (22%) (Sterett and Krisoff, 1994). An for this explanation may be that such skiers are exposed to more difficult slope conditions.

The role of skiing instruction in preventing injuries is considered controversial, and it is argued that that skiing lessons must be coupled with experience to have a positive effect. It is also argued that ski instructors should put more emphasis on proper functioning of equipment and teaching proper falling techniques (Ekeland and Nordsletten, 1994; Johnson and Renstrom, 1994).

6.6.2 Summary

The weight of evidence suggests that beginners and less experienced skiers have a higher risk of injury than advanced or intermediate skiers. The effect of ski lessons on the injury rates of intermediate or advanced skiers is less obvious. An assumption is often made that ski lessons assist in reducing the risk of injury, and do so by increasing a skier's ability more quickly than if the skier did not take lessons. This is likely to be the case. For this and other reasons, ski lessons are to be recommended. Ski lessons have other advantages including orientating skiers to the use of lifts, social contact and fun, the resort and it's layout, slopes suited to their ability and other safety measures.

The effectiveness of ski lessons as a countermeasure, however, has not been evaluated in a formal, controlled way and neither has the specific content of ski lessons. In fact, little of the evidence summarised in Section 6.6.1 is to do with lessons. Most relates to levels of competence, which are assumed to be associated with lesson taking.

6.6.3 Recommendations for research, development and implementation

- The categorisation of skiing ability and history of ski lessons should be standardised in future studies.
- Controlled studies to evaluate the effectiveness of ski lessons for injury prevention should be undertaken.
- A review of the content of ski lessons with respect to skiing safety should be undertaken.

6.7 CLOTHING, INCLUDING EYEWEAR AND SKIN PROTECTION

6.7.1 Background

Clothing serves several purposes in alpine conditions, including protection from a variety of weather conditions such as snow, sleet or rain, high winds, poor visibility, brilliantly sunny days and strong reflective glare. Clothing that is inadequate in providing warmth and wind factor protection can leave the skier at risk of hypothermia and frostbite. Most body heat is lost through the head and trunk, but the fingers, toes and ears are particularly prone to frostbite (Fitzpatrick, 1995).

Skin and eye protection from direct or reflected sunlight are essential even on cloudy days. Ultra-violet protection is of particular importance at high altitudes. Physical exertion in skiing can be intense. Skiers can be uncomfortable if they become too hot and sweat, particularly as they will cool down rapidly upon stopping or resting. Conditions in alpine areas can change very rapidly and clothing needs to be suitable for a variety of conditions (Fitzpatrick, 1995).

Epidemiological studies confirm eye injuries represent a small percentage of skiing injuries (ie they are rare). Reports on eyewear in relation to injury are usually non-specific, but are generally minor and infrequent (approx 18 per year in the USA). Injuries as a result of broken lens glass are extremely rare and almost non-existent since the introduction of eyewear standards. Frames are more frequently mentioned in eye injury reports than lenses (Piziali, 1989).

6.7.2 The effectiveness of clothing, including eyewear and skin protection

The general principle of clothing is to dress in layers that trap air between them, thereby acting as insulation. Clothing can be divided into 2 layers: the inner insulating layer and the outer windproof and water proof layer (Victorian Ski Association, 1995). The number of insulating layers should be selected according to weather conditions and activity levels so the skier remains comfortable (Victorian Ski Association, 1995). The development of a prototype for ski instructors has highlighted the difference between the needs of this professional group and those of recreational skiers in this respect (Laine and Hester, 1989).

It has been suggested that the layer of clothing next to the skin is the most important, and should include warm underwear. Wool is good but can become itchy, and cotton absorbs

sweat and becomes damp too easily. The newer fibres promoted are synthetic (eg polypropylene) and the styles of thermal underwear are designed to allow moisture to move away from the skin. The second layer can be wool or 'fibre pile' materials. Skivvies or jumpers that cover the neck if required in cold weather should also be considered by skiers. The outer layer should be both water and wind proof. To achieve this, garments made of materials such as Gore-tex or Entrant are the most effective (Fitzpatrick, 1995).

Hats, warm socks and gloves are also very important items of clothing as ears, feet and fingers are particularly prone to frostbite.

Hundreds of dollars can be spent on ski clothing, but it is not necessary. For those skiers without their own, protective outer clothing can be hired through most hire outlets (Victorian Ski Association, 1995).

Slippery clothing (with low coefficients of friction) can result in longer sliding distances and higher speed impacts especially on ice and steep slopes. Of all skiers presenting to a Vermont ski clinic between 1972 and 1980, 12% said that their injuries occurred after they had slid some distance (Johnson, 1992). Uncontrolled sliding is also likely to increase the risk of collision with other skiers, obstacles on the slopes, trees, sliding over cliffs, or sliding into creeks that are in the valleys at the bottom of some ski slopes.

Glare from the snow and levels of UV light can be considerable at high altitudes, even on overcast days. Eyewear is essential to protect the eyes from damage and 'snow blindness' that can occur. Ski goggles are generally equipped with lenses that are tinted. The type of lens may be more suitable to conditions of bright sunlight or low visibility and fog. Some goggles have lenses that are suitable, or adapt, to both extremes of visibility, but may be more expensive. Sunglasses are suitable only for fair weather conditions, and it is recommended that skiers always carry goggles as a precautionary measure. If skiers are dependent on spectacles they should carry a spare pair (Victorian Ski Association, 1995).

Ocular trauma from skiing as a sport may not be a major problem. It was not reported as such in a study on Victorian hospital morbidity (Fong, 1995). According to a US review, eye injuries represent a small proportion of injuries in skiing, as do injuries as a result of the use of the eyewear itself (Piziali, 1989).

In the review of literature, no references were identified that considered children's eyewear. Given the generally low standard of equipment such as skis, boots and bindings that researchers have found to be used by children, clothing and eyewear as a countermeasure may need more detailed consideration.

6.7.3 Summary

Appendix 9 summarises the above studies on clothing design and injury prevention. Because appearance and comfort are important, this is an area that warrants particular attention to consumer acceptance.

6.7.4 Recommendations for research, development and implementation

- Continue to improve the materials for skiing garments and eyewear.
- Development and further testing of clothing with higher coefficients of friction should be considered.
- Continue to reinforce the essential and protective aspects of clothing to skiers.

- Continue to encourage the use of protective sun screen.
- Consider a specific review of children's clothing and eyewear.

6.8 SPEED AND COLLISION CONTROL

6.8.1 Background

Speed and loss of control have been implicated in injury. Skiing too fast and out of control or on terrain above a skier's ability can increase the risk of injury. Good skiers reach speeds of about 60 km/h and average skiers about 30-50 km/h (Oh and Ruedi, 1982).

High energy and direct impact falls or collisions have been associated with serious injuries including femoral fractures (Sterett and Krisoff, 1994), splenic rupture and renal injury (Sartorelli et al, 1995), head injuries, and trauma to the nervous system (Oh and Ruedi, 1982; Oh, 1984; Lindsjo et al, 1985; Morrow et al, 1988; Lystad, 1989; Myles et al, 1992; Frierhood et al, 1994; Sartorelli et al, 1995). These may result from collisions at speed, with natural obstacles such as rocks, trees, ski lift or resort equipment, other skiers or persons on the slope, or as the result of a fall in firm or icy conditions.

The prevention of events that can result in major trauma including injuries to the head, neck and nervous system is particularly important because of the potential risk of death or permanent and serious disability. With improvements in equipment, beginners have progressed more rapidly to advanced slopes and higher speeds. Fear can make an anxious skier fall and low energy falls can produce dangerous loading configurations that do not cause binding release.

A review of the records of 145 cases of severe nervous system trauma in skiers admitted over 5 years to 3 hospitals in Calgary, found there were 5 deaths, the mean age of skiers was 23.8 years and injuries were 3 times more common in men than in women (Myles et al, 1992). The types of injury were head injury (88%), spinal cord/nerve root (20%), spinal fracture alone (25%) and peripheral nerve injuries (12%). The mechanism of injury was an isolated fall on the hill in 48% of cases, collisions in a 41%, a fall from a lift in 2% and other or unknown in 9% of cases. These collisions involved trees (23%), another skier (6%), fences (5%), lift equipment (5%), snow-making or grooming equipment (3%) and a ski lodge (2%). Alcohol was documented as being a factor in 3 cases (2%) and may have contribute to the injury in another 3 (Myles et al, 1992).

The mortality rate of 0.81 deaths per million skier days reported by Myles et al (1992), in this Canadian study was higher than the rate of 0.24 trauma-related skiing deaths per million skier days reported in Australia (Sherry and Clout, 1988). Unfortunately, the Canadian study was not able to accurately assess skier ability, attitude and snow conditions from patient records. It was able to determine that 3 of the 5 fatally injured skiers were involved in high speed collisions (Myles et al, 1992).

Males, and skiers less than 19 years of age, were reported to have the highest incidence of depressed skull fractures in one study (Oh and Ruedi, 1982). Males, and skiers less than 17 years of age, had a relatively higher proportion of cervical spine injuries in another study (Oh, 1984).

Head injuries resulting from collisions with lift equipment have been considered in a Swedish study (Lindsjo et al, 1985). Of the 2259 patients treated at ski emergency rooms at 2 ski resorts in Sweden over 3 winter seasons, 258 (11%) sought medical advice for head

injuries. This number had been relatively constant over the years. Of these, 159 sustained their injury while skiing and 99 in the lift queue or on the T-bar lift tracks. The three main mechanisms in head injuries were falls, collisions and blows from swinging T-bars. In those who sustained head injuries in falls, the most common injuries were head contusions with open wounds (44%) and head contusions with concussion (34%). Of the person to person collisions, most injured males had run into someone else, but most injured females had been struck by someone out of control (Lindsjo et al, 1985).

A retrospective survey of 323 patients with skiing injuries admitted to a Colorado trauma hospital found that 107 (33%) were injured in skier-tree collisions, including 7 deaths (Friermood et al, 1994). This group was compared to those not injured in this way. Not surprisingly, the Revised Trauma Score and the Injury Severity Score were significantly higher for the tree-collision group. Those who collided with trees were more seriously injured, with a higher rate of injuries such as skull fractures, head injuries, pelvic fractures and chest injuries. Tibial fractures were more common in the non-tree collision group and femoral and upper extremity fractures were evenly distributed. In the researchers' opinion, the reasons for skiers colliding with trees were not clear. However, they considered crowded slopes and higher speeds of skiers to be an explanation. Another possibility is that these skiers were deliberately skiing through the trees, but in doing so were unable to control their direction or speed well enough.

Skiing falls that involve either high speed impact with trees, lift towers or other stationary objects or low speed simple falls onto moguls have been involved in serious abdominal injuries such as splenic rupture and concomitant renal injury (Sartorelli et al, 1995).

A retrospective analysis (Morrow et al, 1988) of all ski-related accidental deaths in Vermont over the ski seasons from 1979/80 to 1985/86 reported 16 deaths and an estimated rate of one death per 1.5 million skier-days. Most were male (81%) and 62% were between the ages of 15 and 26 years. Collisions with objects, most commonly trees, accounted for 14 of 16 cases. There was a predominance of head and upper body injuries with lethal head and neck injuries accounting for all but two of the deaths. One skier was wearing a helmet. Speed and loss of control were the two major contributing factors identified. Blood alcohol was measured in 13 cases. Alcohol was detected in only one case and that at less than 0.01%

An epidemiological study of collision injuries in Norway involving 883 injured skiers and 379 controls found that 18% of the injuries were due to collisions. Beginners and children accounted for a relatively high percentage of collisions. About 27% of the collision injuries were to the head and about 35% were to the lower limb, in skiers who had collided either with other skiers or with fixed objects (Lystad, 1989).

The countermeasures in this area are orientated towards speed and collision control and safe skiing. They include the education of skiers with respect to behaviour on the slopes, the 'rules of the road' and skiing at safe speeds; the layout of ski slopes to minimise collisions; and more specific speed control programs that may be initiated by ski patrollers. Safe lift equipment and identification and mitigation of hazards are also countermeasures that relate to collision control and are considered in other sections.

6.8.2 The effectiveness of speed and collision control

No studies were identified that formally evaluated speed and collision control. Nevertheless, the review of epidemiological studies in the introduction to this section has

substantiated speed and collision as risk factors for major trauma and injuries to the head, spine and nervous system.

The collision injury rate observed in a Norwegian study reduced over the 5 seasons of the study period, and a reduction in collision injuries was attributed to slope management. New slopes with different degrees of difficulty provided a better separation between skiers of differing ability, and wider slopes reduced the 'collision zone' at the tree/slope border (Lystad, 1989).

Collisions may occur where slopes intersect. The separation of ski runs and slope management Have been highlighted as countermeasures (Alpine Safety Conference, 1995).

Collisions with hazards including lift and resort equipment such as snow making or grooming machines, suggests a greater need for the adequate identification of such hazards and the provision of protective padding where necessary. The number of injuries sustained from swinging T-bars noted in a Swedish study (Lindsjo et al, 1985) seems high. It is possible that these may be the main, or only lift, at these resorts, but this was not clear. The nature of the collisions in this study also suggests that women may take sufficient care as to where or when they stop on the slope, or start skiing again. An alternative suggestion is that males are more reckless. It is noteworthy that the Swedish resorts did not use ski patrols during the period of the study (Lindsjo et al, 1985). The authors considered that supervision by ski patrols may be a good idea.

The 'Skier Safety Code' in the "SnowSafe" safety booklet also highlights responsible skier behaviour with respect to skiing in control, ability to stop when necessary, and avoiding stopping where a trail would be obstructed (Victorian Ski Association, 1995).

Ski patrollers are well aware of the involvement of speed and collisions in injury. Ski patrols monitor injury rates throughout the season (Alpine Safety Conference, 1995). A number of skiers sustained head injuries at one Victorian resort during the 1995 season. A component of the ski patrol's response to this was the implementation of a speed control program. This involved skier education on the reasons for speed control, warnings to skiers who were skiing too fast, or depending on the circumstances temporary or permanent lift ticket confiscation. Skiers were reportedly responsive to the program. The injury rate declined and patrollers considered that the program played some part in this (Pelly, 1995).

The involvement of T-bar ski lifts in head injury incidents has been highlighted in one study (Lindsjo et al, 1985) and protective measures in relation to this type of lift equipment may need greater consideration.

6.8.3 Summary

No studies were identified that formally evaluated speed and collision control. Nevertheless, the review of epidemiological studies in the introduction to this section has substantiated speed and collision as risk factors for major trauma and injuries to the head, spine and nervous system.

6.8.4 Recommendations for research, development and implementation

- Skier education programs relating to safe skiing should continue or be increased.
- Consideration should be given to determining the most effective means of prevention high speed incidents and collisions.

- Skier education programs should be targeted to certain groups (eg young males) and the hazards of reckless skiing.
- Speed control programs, at the discretion of ski patrollers, should be supported.
- Methods for evaluating the effectiveness of speed control programs should be explored and built into routine ski patrol activities.

Improved ways of reducing the potential for injury from lift and resort equipment should be considered.

6.9 PROTECTIVE HEADGEAR

6.9.1 Background

The epidemiology of head injuries in skiing have been discussed in relation to speed and collision control in the preceding section. Yet there are no standards in Australia or world-wide, for protective headgear for skiing. The wearing of protective headgear is mandatory for downhill skiers in Olympic and World Cup competition. The National Alpine Commission and the World Alpine Commission have also imposed mandatory helmet wearing for all children whilst racing or training for racing (Carey, 1996). Wearing of headgear is voluntary for senior and adult racers, though it is becoming increasingly accepted and usage rates are increasing. The use of helmets by children generally, is being promoted by resorts, alpine safety authorities and peer-group influences (Carey, 1996).

Cervical spine injuries have been considered in relation to the protective value of helmets (Oh, 1984). The usual position of the skier's head (especially at high speed) is similar to the boxer's head position, ie with the head forward and the shoulders raised. In direct collision the head hits first (mainly the forehead) normally causing direct head damage. The flexible portion of the neck receives secondary force from the impact. Anterior-posterior rebound (ie forward and backward motion) blows and a fracture dislocation of the cervical spine can result.

In acknowledging that not all head injuries can be prevented, it has been proposed that headgear should be targeted towards those that can be prevented. In turn, what headgear is intended to prevent depends on the level at which skiers are participating in the sport, eg professional vs recreational (Morrison, 1995).

Sport specific head protection is considered important, but the cost of providing such protection for a number of different sports in which an individual may participate can be considered by some to be prohibitive. In Australia, the available ski helmets typically range from \$70 to \$140. A Melbourne-based researcher and authority on protective headgear (Morrison, 1995) is developing a generic shell to which components can be added or removed for participation in different sports (eg skiing, football, cycling). Such a helmet has the potential to reduce the cost for parents purchasing such equipment for their children or for adult participants themselves. Newer materials, such as polymers and polystyrene, provide the helmets with more resilience and a longer life. Morrison (1995) is aiming for the adoption of an international standard in 1996.

Through design, the headgear must reduce lacerations and concussion (as not all can be prevented), and the materials should reduce the impact of forces that might be applied. Other considerations are the reduction of skull and facial bone fractures and injury-induced fits, and the fact that headgear should also protect against lesser impacts (Morrison, 1995).

Dangers introduced by head protection include (Morrison, 1995):

- increase in mass and size of the head (with subsequent stress on weaker structures such as the neck that may not be capable of taking the motion or the strain)
- reduction in visual and auditory functions
- potential use of the head as an offensive weapon or as a handle by the opposition in some competitive sports.

This latter danger is unlikely to be of relevance to helmets for skiing and it is more of a problem for contact sports. The possibility that head protection will make sportspersons more reckless is reported to be more relevant to older than younger age groups (Morrison, 1995).

6.9.2 The effectiveness of protective headgear

The local application of force on the skull can lead to depressed fractures, and the force of the impact and injuries sustained depend on the speed of impact (Oh and Ruedi, 1982). Collision control is an example of a primary injury countermeasures and protective headgear is an example of a secondary countermeasure for the prevention of injury. Speed control is both a primary and a secondary prevention method. Measures to reduce speed and collision related injuries, as well as the potential of protective headgear, therefore also need to be considered in any program to reduce head injuries.

Swedish researchers have reported that the use of helmets is widespread among young skiers in Sweden. They also note, however, that whilst helmets do prevent injury, they do not prevent the event that may lead to injury. Furthermore, they argue that design problems can limit sight and hearing while skiing in a helmet (Lindsjo et al, 1985). This study is more than ten years old and its applicability to modern helmets could be questioned. Modern helmets do not restrict hearing or sight whilst skiing (Carey, 1996).

Some researchers have promoted the protective value of safety helmets (Oh and Ruedi, 1982; Oh, 1984) for preventing head injuries in skiing. However, their opinions were not based on formal evaluation in trials or case control studies.

Considering 18 cases of cervical spine or head injuries, the researchers considered that in the position assumed by skiers at high speed, a back extension would provide additional protection for the cervical spine (Oh, 1984). Furthermore, a safety helmet and prevention measures could reduce head and neck injuries (Oh, 1984). However, this recommendation for an extended posterior section to the helmet as a protection against cervical injuries was not substantiated by biomechanical evidence or controlled trials. Other researchers have considered that an extension to the posterior part of the helmet would limit extension of the neck. This is essential in the 'tuck' position and would not protect against the flexion or axial loading injuries that were seen in 12 of 45 cases with spinal injury (Myles et al, 1992). This was also based on expert opinion rather than biomechanical evidence or controlled trials.

As part of their response to a number of skiers sustaining head injuries at one Victorian resort during the 1995 season, ski patrollers implemented a program of preventive measures. These included a speed control program and promotion of protective headgear, with ski patrollers using them as an example (Pelly, 1995). All children in classes in the ski school program at Mt Buller will be wearing protective headgear during the 1996 season (Lyons, 1995).

6.9.3 Summary

Expert and informed opinion suggests that properly designed protective headgear should help protect against head injuries. The use of such headgear may be appropriate to all skiers or more so for certain groups of recreational skiers such as children. As a countermeasure for injury prevention in skiing, the effectiveness of protective headgear has not been formally evaluated. It has been suggested that current helmet design may interfere with vision and hearing, which may result in cues that are important to skiers in the prevention of collisions being lost to skiers. However, there is no formal proof that this should be the case. Indeed, modern helmets provide perforations or holes for the ears to assist with hearing. The cost, comfort, colour and design are features that may influence consumer acceptability. Risk factors such as speed, environmental hazards and skier behaviour need to be considered in any strategy or program to reduce head or cervical spine injuries.

The two studies that have looked specifically at the issue of protective headgear are summarised in Appendix 10. Clearly, a lot more research needs to be undertaken, as the recommendations in the following section suggest.

6.9.4 Recommendations for further research, development and implementation

- Further research into the development and improved design of protective headgear is needed before it is widely promoted.
- The development of generic protective headgear that is adaptable to different sports should be endorsed.
- Research into skier's attitudes towards, and acceptability of protective headgear, should be undertaken.
- Once there is a suitable prototype available, controlled trials on the ski fields should be undertaken to determine the effectiveness of protective headgear.
- The development of standards for protective headgear should be considered.

6.10 ADEQUATE NUTRITION AND REDUCED ALCOHOL INTAKE

6.10.1 Background

Controversy surrounds the relationship between injury risk and alcohol use in alpine skiing (Meyers et al, 1996). It has been argued that alcohol, alone or in combination with other drugs, increases the risk of injury or more serious injury (Meyers et al, 1996). Other studies have not.

The use of alcohol may potentiate hypothermia in a cold environment, and alcohol-induced unconsciousness or stupor in the mountain environment may increase this serious risk. Consumption of alcohol the night before, or during a skiing day, may interfere with concentration, coordination and reflexes and increase the risk of injury.

Injuries are more likely to occur at certain times of the day, such as late morning and late afternoon, and fatigue at such times may contribute to the risk of injury (Sterett and Krisoff, 1994). Adequate rest, nutrition and energy replenishment may enhance performance and prevent injury.

6.10.2 The effectiveness of alcohol reduction and adequate nutrition

A study of alcohol consumption by skiers during breaks found that, of injured skiers 79% never consumed alcohol, 18% sometimes and 3% did so every day. This can be compared to uninjured skiers amongst whom 67% never consumed alcohol, 28% sometimes and 6% every day. With respect to daily average alcohol consumption for injured skiers, 61% consumed 0,1 or 2 glasses and 15% consumed 5 or more glasses per day. Amongst non-injured skiers, 53% consumed 0,1 or 2 glasses and 23% consumed 5 or more glasses (Bouter and Knipschild, 1991). These percentages seem quite high, especially considering that they may be under-reported as the study population consisted of Dutch skiers who were making claims through their insurance company.

The authors of this study also cited studies in German, which reinforced their argument that perceptible blood or breath alcohol levels are, in fact, rare in injured or uninjured skiers (Bouter and Knipschild, 1991). Moreover, alcohol consumption is neither a major risk factor in skiing nor is it a preventive factor.

A low prevalence of a potential risk factor such as alcohol consumption in a population, makes the study of alcohol involvement in skiing injuries difficult. On the other hand, if consumption is uncommon then it can be discarded as a potential risk factor.

American researchers, Meyers et al (1996), identified some of the methodological difficulties associated with investigations of alcohol use and skiing. Among these were the temperature limitations of the breath analyser equipment and the potential for underestimating alcohol levels. They made specific suggestions for improving the methods used in future studies.

On the basis of their results, Meyers et al (1996) suggested that specific countermeasures to reduce alcohol-related ski injuries should highlight responsible drinking before skiing and the associated dangers of residual alcohol effects. They argued that these should be directed towards high-risk skiers (eg younger females and especially those who may be more cautious and do not customarily drink and ski), less experienced skiers, those skiing early in the season and those skiing on holiday weekends.

Alcohol consumption may theoretically acutely increase the risks of skiing. It can influence reaction time, accuracy of movements and the perception of risk; and in the long term a lowering of the intake of carbohydrates thus hampering the glycogen resynthesis and increasing the risk due to exhaustion and decreased movement control (Brouns et al, 1986; 83).

Effective injury prevention will not be achieved if skier education is handled in a loose, non-specific way. Education may be ineffective (Bouter and Knipschild, 1991), but it may also be unfair to make skiers feel guilty about even a moderate intake if this is prematurely decreed as being a risk factor for injury.

Brouns et al (1986) reviewed the literature on nutrition as a factor in the prevention of injuries in recreational and competitive downhill skiing. While not identifying any clinical trials, the articles reviewed reported evidence of glycogen depletion during exercise, and tiredness at times of injury. Time and energy requirements for muscle recovery and increased carbohydrate requirements during and after exercise, were identified.

Two options were proposed for enhancing glycogen repletion or a sparing effect. These were to train the body in a way that glycogen will be limited and to take care of optimal

nutrition in periods of intense recreational or competitive skiing. For the recreational skier, specific suggestions were made for foods and timing of meals/snacks, including a small carbohydrate rich meal immediately after skiing, in order to increase carbohydrate intake and replenish muscle glycogen levels. It was recommended that alcohol consumption during apres-ski be limited as this may influence food and carbohydrate intake negatively (Brouns et al, 1986).

A study (Tesch et al, 1978) of a limited number of highly skilled and relatively unskilled skiers was conducted to determine nutritional requirements and selective glycogen depletion patterns for different types of muscle fibres, as well as anaerobic metabolism in terms of lactate accumulation. The type of skiing and intensity were not the same in both groups and this limits the comparison. Nevertheless, the study found that skiers of greater proficiency had a relatively greater aerobic energy output during skiing, and this was confirmed by oxygen uptake determinations. There were differences in glycogen depletion patterns across the groups, but lactate accumulation failed to differ between skilled and unskilled subjects.

6.10.3 Summary

The weight of evidence suggests that levels of alcohol consumption in skiers are not clear, nor is the effect alcohol consumption may have on the risk of injury. The prevalence of measurable blood alcohol amongst skiers may be lower than expected. This has not been studied in Australian resorts. There are methodological difficulties associated with the estimation of blood alcohol levels in skiing. There are also practical difficulties in the measurement of blood alcohol concentration with a breath analyser in very cold conditions. The dangers associated with hypothermia in a mountain environment and the evidence of the effect of blood alcohol levels on coordination, concentration and reflexes in other research are well recognised. Given this, it would seem prudent to caution skiers to consider their alcohol intake and the potential effect it may have on skiing performance, and not to drink alcohol during skiing breaks.

The evidence suggests that adequate carbohydrate (and nutritional) intake and replenishment during and after skiing is important and to be recommended.

6.10.4 Recommendations for research, development and implementation

The studies examining the role of alcohol intake in injury causation are summarised in Appendix 11. These studies, together with the evidence cited above, lead to the following recommendations.

- Reinforce the importance of good nutrition and adequate carbohydrate replenishment during skiing.
- Conduct preliminary studies on the alcohol consumption patterns of Australian skiers to determine the extent to which may be a factor in injuries.
- Controlled studies on the relationship between alcohol consumption and skiing injury occurrence are needed - but these should be based on the results from the above recommendation.

6.11 STANDARDS FOR SKIING EQUIPMENT

Standards Australia has emphasised the need for relevant and technically reliable and accurate Australian standards. Standards Australia has a policy of adopting an international standard wherever an appropriate one is available. In developing a new standard, a genuine need and the support of a community or interest group needs to be demonstrated (Standards Australia, 1995).

The development of skiing standards began in 1972 when the American Society of Testing and Materials (ASTM) became involved with the formation of Subcommittee F08.14 on Skiing within Committee F-8 on Sports Equipment and Facilities. It progressed to full committee status in 1982, as Committee F-27 on Snow Skiing (Roberts, 1992). Roberts (1992) presents a brief overview of each of the snow skiing standards that have been developed to date and comments on how the standard is expected to enhance skiing safety. The author discusses the concerns of the committee and identifies issues related to research and future standards development (Roberts, 1992), including:

- additional standard on specifications for ski binding testing devices
- skiing helmets
- ski poles
- snowboard binding screws
- testing of ski/boot binding systems by ski shops and skiing rental operations
- stiffness of ski boots.

Standards that were referred to included:

- Test Devices for the Adjustment of the Functional Unit Ski/Binding/Brake/Boot; DIN 32 921 German Industrial Standard, Beuth-Verlag GmbH, Berlin, 1982 (Nagel and Mosch, 1987)
- Release bindings for alpine downhill skiing; terms, technical requirements of safety and testing; DIN 7881 Vol 1, German Industrial Standard, Beuth-Verlag GmbH, Berlin, 1982 (Nagel and Mosch, 1987)
- Assessment, combination, mounting and setting of the functional unit ski/binding/brake/boot; DIN 32923 German Industrial Standard, Beuth-Verlag GmbH, Berlin, 1984 (Nagel and Mosch, 1987)
- Winter sports equipment-release binding for alpine downhill skiing for children; DIN 7881 3-5 (Gundersen, 1987).

A search was conducted by Standards Australia on the World-wide Standards Index on CD-ROM (1995/96 issue) for the US Database. The keywords of helmet, sport and recreation were used. Nothing was located on standards that specifically related to skiing, skiing helmets or bobsled helmets.

A similar search on the International European Database located relevant standards that included:

- DIN 33952. Protective sports helmets: ski helmets; safety requirements, testing. Publication date 1988.

- DIN 33953. Sports protective helmets: bob helmets; safety requirements, testing. Publication date 1989.
- DIN EN 1077. Helmets for alpine skiers; German version prEN. Publication date 1993.
- DIN 5333. Ski goggles: safety requirements and testing. Publication date 1986.
- DIN EN 174. Specification for personal eye protection; ski goggles for downhill skiing; German version prEN 174. Publication date November, 1993.
- DC 93/309042. Personal eye-protection. Specification for ski goggles for downhill use (prEN 174). Publication date August 1993.

6.11.1 Recommendations for further standards development

- A review of Australia's policy regarding skiing equipment and requirements in relation to equipment standards should be undertaken.
- A review of Australia's policy regarding training and standards for ski shop personnel, ski binding fitting and adjustment in retail and hire outlets, and the use of test devices for binding adjustment needs to be performed.
- Based on the results of these two reviews, Australian policies may need to be reviewed and revised.

6.12 SAFE LIFT EQUIPMENT

Part of the development of ski resorts involves the installation of lift systems to take skiers, and downhill skiers in particular, to the top of ski runs. The type of lifts available include poma lifts, T-bar lifts, chair lifts, and gondola lifts of various sizes. With poma and T-bar lifts the skiers remain on the snow whilst being pulled up the hill. They then detach from the poma or T-bar at the top of the hill, and the equipment then travels back overhead to the loading station at the bottom. Skiers using chair lifts have to get on and off the lifts, usually while the chairs themselves are moving. For most lifts, lift attendants assist skiers to board the lift. An attendant is usually stationed at the top lift station, but will generally assist skiers only if necessary. The boarding and alighting of lifts, and the swinging of T-bars have been implicated in injuries to skiers. The pylons or towers of ski lifts also present a hazard to skiers in terms of collision.

Most of the injuries reported in a Swedish study on T-bar related injuries were not serious (Lindsjo et al, 1985). The mechanism of injury was a blow from a T-bar (just over 50%), a fall in the lift queue (30%), being caught by the T-bar (6%) or run into a T-bar(3%). The site of injury in 96% of cases was the head, and most of the blows from T-bars caused wounds on the face or scalp (78%). Nine skiers sustained head contusions without open wounds, of whom 4 showed slight concussion and 4 dental injuries. Of the injuries associated with falls, nearly half were sprains affecting the knees, ankles or thumbs. The injury rate was 1 injured skier per 79,718 T-bar lift runs.

The focus of this Swedish study was T-bar related injuries (Lindsjo et al, 1985). The extent to which T-bars are the major, or only, lifts at Swedish resorts was not clear. Some of the T-bars were unmanned, which is not generally the case in Australian resorts. In another study from their area, the researchers reported that 62% of head injuries occurred in the lift tracks or lift queues (Lindsjo et al, 1985).

There is generally little information available on the injuries associated with ski lifts, and no studies that compared injuries between different types of lifting systems. The process of getting on and off lifts is an event that could well be associated with falls or injury. How smoothly it goes can depend on the ability of the skier, the type of lift, maintenance of the area for getting on or off the lift, the instructions and assistance provided to skiers from lift attendants, and the ability of the other skiers who may be travelling on the lift at the same time in the case of T-bars or chairlifts. Skiers can also collide with lift towers, which need to be adequately visible and padded as necessary.

Many resorts are now phasing out the use of T-bars and drag lifts, in favour of chair lifts (Carey, 1996). This review was unable to find any literature that assessed whether the injury patterns had changed because of this.

6.12.1 Recommendations for further development, research and implementation

- Further research into the extent of lift associated injuries and how to minimise them is needed.
- Data on lift associated injuries should be routinely collected as part of resort management or as part of ski patrol reports.
- Monitor injury rates at resorts where chair lifts have replaced T-bars and drag lifts to determine the impact on injury rates.

6.13 ENVIRONMENTAL CONDITIONS, SLOPE AND TRAIL DESIGN, GRADING OF TRAILS, SIGNAGE, ACCESSIBLE UPDATED INFORMATION ON CONDITIONS, IDENTIFICATION AND MITIGATION OF HAZARDS.

6.13.1 Background

Many of the hazards of skiing will never be completely removed from the sport, and to do so may detract from the aesthetic beauty of the skiing in the mountains or the appeal of skiing as a vigorous adventurous sport (Penniman, 1993). Some potential hazards such as ski lift towers are an unavoidable component of the resort structure, and trees provide shelter, protection against erosion, natural beauty and reference points in poor visibility. It is generally accepted by skiers and the ski industry that it is the skier's responsibility to ski in a responsible manner, to visually assess the slope and snow conditions below them, and decide whether or not he or she has the skills necessary to successfully negotiate the slope. However, potentially hazardous slope conditions may not be visible simply by looking down the slope from above (Penniman, 1993).

A review of the practice of using visual markings and signs to give warning and direction to skiers for potentially hazardous conditions has described a number of important factors including (Penniman, 1993):

- the role of the professional patroller in any successful program for hazard marking
- the removal of signage once it is no longer required
- the importance of communication between different departments on the mountain
- methodology of hazard marking (the types of hazards, methods of hazard marking, the hazards that require warnings and those that require barriers)

- typical hazard marking materials
- typical formats for warnings and for barriers
- typical signs
- padding of obstacles
- methods of traffic control (signs, wing fences, mazes, speed patrollers).

This review (Penniman, 1993) also emphasises that while a custom and practice for identifying and mitigating common hazards at US ski areas has developed, no uniform safety standards have been written or officially adopted. The unwritten policy or practice in each ski area may vary, and may not be clearly understood by the skiing public or even by the professional ski patroller.

Injury in skiing areas has been the subject of litigation, with plaintiffs claiming that their injuries were a direct result of failure to remove or warn against a common hazard (Penniman, 1993).

A consistent policy of hazard mitigation is important, for both skiers and the ski industry, in any program to reduce skiing injuries. Trail design, removal of obstacles, summer grooming and winter slope grooming are all important measures to help prevent injuries. All Australian resorts groom their major trails regularly (Carey, 1996)

Measures taken by professional ski patrollers or resort management in Victoria include:

- grading of ski slopes according to degree of difficulty with standardised signage: 'easiest' denoted by a green circle, 'more difficult' by a blue square, 'most difficult' by a black diamond or 'run closed'
- slope signs such as 'slow down', 'trails merge', or 'hidden obstacles'
- trail design to avoid intersections and congestion
- trail design to separate advanced and beginner skiers
- summer grooming and maintenance of ski slopes
- winter slope grooming
- removal of obstacles, where possible, or alerting skiers to their existence through signage and barriers on slopes
- visible, updated information on slope and weather conditions.

To promote skiing safety in the newly developed ski area for the 1994 Winter Olympic games in Norway, the following were established (Bergstrom et al, 1993):

- a ski school
- a shop for ski rental and binding testings
- a rescue team based on the ski patrol
- a questionnaire for registration of skiing injuries - with the abbreviated injury scale (AIS) and the injury severity score (ISS) calculated for all injured skiers and mapped for each ski slope
- grading of the ski slopes (colour coded according to skiing ability and the ISS that was calculated for each slope)

- a corrected ISS formula depending on the total number of lift transports, the total skiing length in metres and the total transportation height in metres.

Mapping of the AIS and ISS data enabled ongoing assessment of skiing injuries and safety on the slopes, the severity of injuries and the difficulty of the slopes. It also enabled interventions to be reviewed. The corrected ISS provided a figure that would enable a score for the whole area to be used as an indicator of progress in reduction of injury from one season to the next and from one centre to another (Bergstrom et al, 1993).

Ski patrols report that they use injury data collected throughout the season to monitor injury rates and take targeted remedial action, if patterns appear. The effectiveness of various methods of hazard identification and mitigation have not been formally evaluated. Standardisation of policies and methods for hazard identification and mitigation and injury severity scores assist in comparisons of techniques and resort areas, and the monitoring of the effectiveness of interventions.

The major study examining the role of safe lifting equipment and injury prevention is summarised in Appendix 12.

6.13.2 Recommendations for further research, development and implementation

- Pilot testing of a procedure for the calculation of injury severity scores and corrected injury severity scores to aid in ongoing assessment of slopes.
- More formal evaluation of the effectiveness of hazard identification and mitigation in injury reduction is needed.
- Standardisation of policies and methods for hazard identification and mitigation

6.14 SKI PATROLLERS, FIRST AID ON THE SKI SLOPES, RESCUE EQUIPMENT AND GENERAL RESORT SAFETY

6.14.1 Background

The organisation of emergency services, selection and maintenance of equipment, administration of first aid treatment, transport and the use of trained personnel have been identified as important aspects of a first aid service for skiers (Allan, 1976).

Under the Alpine Resorts Act of 1983 the Alpine Resorts Commission has the overall responsibility for resort safety, even though lift companies lease resorts and the ski slopes. If the Act changes, the emphasis or responsibility could also change.

Legislation, including the Ski Safety Act of Colorado, was a topic of presentation and discussion at the 1995 Alpine Safety Conference. Part of the discussion revolved around acknowledgment of the dangers and risks inherent in snow sports and the rights of persons engaged in such sports to recover damages from a ski area operator for injuries resulting from inherent dangers and risks.

In the Canadian province of Quebec, the Quebec Sport Safety Board (QSSB) was created in 1979 by an act of the National Assembly of the province of Quebec. It is responsible for "supervising the personal safety and integrity in the practice of sports" and is unique in Canada (Regnier and Goulet, 1995). The events leading to creation, mandate, legislative

and regulatory powers, and some particular interventions are described by Regnier and Goulet (1995). The QSSB is empowered to:

- gather, analyse and disseminate information on sports safety
- conduct, or cause others to conduct research on sports safety
- educate the public on safety in relation to the practice of sports
- prepare safety training methods for those who work in the sports field
- give technical assistance to sports federations or unaffiliated sports bodies in preparing safety regulations
- assist any person requesting advice on means to ensure sports safety.

With respect to alpine sports in particular, the owners of ski resorts are responsible for resort safety and the enforcement of regulations applicable to resort safety (Goulet, 1996). Standardisation has been a key concern with resort owners having the responsibility for implementation and enforcing standards. This includes the standardisation of signs indicating and reflecting the degree of slope difficulty; standards for first aid personnel (eg minimum education); standards for first aid equipment; slope grooming equipment regulations (including movement of such equipment on the slopes); a code of conduct for alpine skiers and snowboarders, including a speed control policy (Goulet, 1996).

The Ski Patrol plays a valuable role in Australian alpine sports safety, with both professional and trained volunteer patrollers. Victoria has ski patrollers located at 7 resorts: Mt Hotham, Mt Buller, Falls Creek, Mt Buffalo, Lake Mountain, Mt BawBaw and Mt St Gwinear.

Ski patrollers perform a multitude of functions that relate to all stages of injury prevention, including:

- ski patrols on the slopes throughout the day
- on-slope skier education
- education of junior and school groups
- speed control programs
- response to reports of skier difficulties or injuries
- provision of first aid on the slopes
- transport of injured skiers to medical or ambulance services
- search and rescue for lost skiers
- collection of data on the 'Ski Patrol Accident Report' form
- data entry and analysis
- ongoing injury surveillance throughout the season
- hazard identification and mitigation throughout the season
- advice to resort management
- review and comparison with other resorts at the end of the season

- training and education of applicants and existing members in skiing and mountain rescue techniques, first aid knowledge and qualifications.

Patrollers may also be called to assist skiers who are in difficulty, even though they may not actually be injured. This is also registered as a call-out in their report forms.

A speed control policy aims at making skiing safer for all skiers. The actions taken against offenders are progressive, depending on the circumstances. An action can involve speaking to the skier regarding the risks of injury or confiscation of the skier's lift ticket for a 2-3 hour period or permanently. Skiers are generally responsive to the less severe measures (Pelly, 1995).

Ongoing injury surveillance can identify slopes or trails where a number of injuries have occurred and assist in focusing hazard identification and mitigation and injury prevention. Action may involve advice to resort management, a speed control program, promotion of safety helmets, trail or ski run closure, signage or obstacle markers or avalanche danger control. Ongoing surveillance can also assist in evaluating the effectiveness of interventions.

Data collection is an important component of any injury control program. Ski patrollers have collected data as part of their routine work for many years. However, data is not collected in the same format at all Victorian resorts, nor is it consistent with that of NSW resorts. The variability of skiing conditions throughout the season, and from one season to the next, also makes comparisons difficult. The standardisation of data collection across all Australian resorts would provide an improved data base for research, statistical comparisons, surveillance, the monitoring of injury trends and evaluation of the effectiveness of interventions or injury control programs.

In search and rescue operations, the successful use of the Global Positioning System (GPS) was presented at the 1995 Alpine Safety Conference. The traditional navigational aids of map and compass have limited capabilities under white-out or blizzard conditions, especially in non-resort or remote areas. The GPS enables search and rescue teams to plot their position on to a topographical map whilst in the field and to relay their position to base. Other advantages of use of the GPS are that it saves time and expense in a search and rescue operation, reduces the likelihood of severe exposure injuries to lost skiers, increases the personal safety of the rescuers, allows more rapid progress in adverse conditions and increases user confidence on the ground, and it is a useful navigation and locational aid in field emergencies.

In presenting the advantages of such a system, it was noted that attention needs to be paid to the operational aspects of the GPS, including planning, training of users and purchase of equipment. The estimated cost of a GPS unit is approximately \$1,200. It was proposed at the 1995 Alpine Safety Conference that all ski resorts should have at least one GPS unit.

Access to the mountain is another aspect of resort safety. Driving in the mountains can be hazardous. There is a legal obligation for those entering mountain areas to carry and fit wheel chains as directed. Driver skill and care are important. The quality of wheel chains was also considered important, and the performance of diamond pattern chains in terms of safety was the topic of a presentation at the 1995 Alpine Safety Conference.

6.14.2 Recommendations for further research, development and implementation

- Review the incident/injury report forms used by ski patrollers to maximise the use of information for injury research and monitoring.
- Consider methods for the collection of injury severity data and the potential for standardisation of this.
- Standardise data collection by ski patrollers and all Australian ski resorts.
- Standardise the age groups used for statistical comparisons in the analysis and reporting of injury data.
- Further develop injury surveillance programs for a range of snow sports
- Continue to support for the Ski Patrol Association.
- Make available of at least one GPS unit at all ski resorts
- Continue to promote safe driving in the mountains.

6.15 SKIING INJURIES IN CHILDREN

Skiing is a sport that can be enjoyed by the whole family. Patterns of injury in children that are different to those of adults. The review of countermeasures such as ski bindings and their adjustment, and ski boots, has highlighted deficiencies in the standard of equipment for this particular group of skiers.

A three year study from 1988-90 of injured skiers presenting to the Mt Hotham Medical Centre, Victoria analysed 2501 injuries (Giddings et al, 1993). Of these injuries, 204 involved children 12 years old or younger. The incidence rate for children was 3.34 per 1000 child visitor days. This was not significantly different to that of 3.05 per 1000 visitor days for skiers aged 13 years or older. Children sustained proportionately more fractures and fewer dislocations than adults. Children also suffered proportionately more head and face injuries and more lower body injuries. The incidence of ligamentous knee injuries was similar in both these age groups, but the rate of lower leg fractures was six times that of adults. Knee sprain/strain was the most common injury in children (35.9%) and lower leg fracture the second most common (9.2%). Thumb injuries were virtually non-existent in the younger group (only 1 case) (Giddings et al, 1993).

Possible explanations are that the bones of children are weaker but more elastic than those of adults, more children are beginners and ski on borrowed or rented equipment that is poorly maintained, and that the improvement in adult boot and binding equipment over the last 20 years has not met the needs of children (Giddings et al, 1993).

A comparative study of 1158 adult and 159 child injuries in Perisher Valley resort, NSW, in 1984 defined child skiers as those less than 14 years of age. The child injury rate of 3.92 injuries per 1000 skier days was not significantly different to the adult rate. Children sustained significantly higher proportions of fractures and fewer dislocations than adults. Children also sustained significantly more injuries to the lower leg, femur, and neck and back region and fewer to the upper limbs. Knee sprain accounted for 28% of injuries, and tibial fractures for 12% (Sherry et al, 1987).

Sherry et al (1987) reported that in relation to risk factors for injury, more children than adults reported the role of the following factors: beginner ability, collisions reasonable snow coverage, borrowed or rented equipment, and wearing of head protection. For

children, fewer bindings released at the time of the fall. In relation to severity of injury graded on a scale from 1 to 5, children sustained more Grade 4 injuries (including fractured femurs), a similar frequency of Grade 1 and 3 injuries and fewer Grade 2 injuries. There were no Grade 5 (threat to life) injuries in either group (Sherry et al, 1987).

Skiing injuries in 59 children under 15 years age were recorded for four Norwegian ski resorts during 1985/6 and compared with a control population of 63 uninjured children randomly selected from lift lines in the same resorts (Ekeland et al, 1993). The most common sites of injury were the lower leg (24%), knee (20%) and head (14%). Forty-seven of the injuries were defined as lower extremity equipment related injuries, and most of these were due to inadequate binding release function. Only 43% of the bindings of injured children, less than 10 years, released during the event, whereas 73% of the bindings for children 10-14 years of age. Skiers under 10 years were thus considered more than twice as "prone" to a lower extremity equipment related injury as those 10-14 years.

Of the lower extremity equipment related injuries in the above study (Ekeland et al, 1993), fracture of the lower leg was the most serious and accounted for 21% of injuries in those less than 10 year old, and 10% in the 10-14 year olds. The older children suffered more head injuries (18%) compared to younger children (5%). Beginner status was considered the most important risk factor. Beginners had a nine-fold increased risk of injury, and skiing experience of three or more seasons reduced the risk. Intermediate skiers were under-represented among injured skiers.

A significantly higher rate of tibial fractures was also observed in children aged 13 years and under in a Vermont study (Blitzer et al, 1984). However, a comparison of injury rates between the two four year periods of 1972-5 and 1977-80 demonstrated a decline in the frequency of such fractures in both children and adults.

Similar concerns about lower limb injuries in child and adolescent skiers were expressed in an earlier four year study, from 1971 to 1973, in Seattle (Garrick and Requa, 1979). Nearly one half (48.9%) of all injuries were sprains or fractures of the lower extremity. Sprains accounted for 51% of injuries, with the most common sites being the knee (47.7%) and ankle (35.2%). Fractures accounted for 11.1% of injuries and nearly two-thirds involved the leg and ankle (33% and 28% respectively), while 23% involved the upper extremity.

In reflecting on a study of alpine skiing injuries in children, the researchers considered that the lower rate of head injury in younger children may have been due to more common usage of helmets in this age group. (Ekeland et al, 1993). They also recommended helmets for adolescent skiers. Helmet usage, however, was not reported in conjunction with the injury data, so the validity of their conclusions cannot be verified.

An Italian study of injuries in 587 children, during 1988-92, found 63% of the injuries were fractures, and over 13% were cranial (30% with concussion) (Molinari et al, 1994). Leg injuries accounted for about 27% of all injuries and 43% of fractures. Collisions were involved in 12 to 15% of injuries. Injured children were generally less skilful skiers and ran a higher risk of injury at the start of the ski season. The most common causes of injury events were crossed skis (25%), high speed (19%) and collision with a large snow drift (10%). Of these, 87% involved the skier and 13% involved collisions (Ungerholm and Gustavsson, 1985).

Junior safety programs such as the 'Gumnut Program' at Mt Hotham have been introduced (Alpine Safety Conference, 1995).

The vulnerability of children to the cold and to hypothermia was highlighted by an Australian study of hypothermia among resort skiers in the Perisher Valley area of New South Wales (Sherry and Richards, 1986). Eleven out of nineteen cases (58%) of accidental hypothermia, diagnosed in patients presenting to a ski injury clinic in the Perisher Valley resort, were in children aged less than 14 years. Approximately 12% of skiers in Perisher Valley are less than 14 years. This age group is therefore disproportionately represented in this serious and potentially lethal disorder. Contributing factors may be the relatively larger ratio of body surface area to volume in children, inadequacy of clothing especially poor lower limb insulation, becoming and remaining wet in a cold environment, and a tendency to ignore the symptoms of hypothermia (Sherry and Richards, 1986). In fact one of the known problems of hypothermia is a failure to recognise it.

In summary, the rates of lower leg and head injuries in children need particular attention. The high rate of lower leg fractures, and tibial fractures, is of particular concern. There is also a need for more studies and analysis of children's injuries, ongoing surveillance in relation to these, and consideration of countermeasures to reduce skiing injuries in children. Helmet usage has not been formally evaluated for its potential or actual effectiveness in injury reduction in children or adults. Attention needs to be paid to preventing hypothermia in children and young adolescents who are particularly at risk of this condition.

6.16 SKIING INJURIES IN MATURE SKIERS

The trend is toward a general aging of the population. Consistent with this is an increasing number of over-65 year olds (mature adults) who are participating in skiing, according to a review of alpine skiing and the mature athlete. Many of the physical attributes required for skiing, such as flexibility, strength, power, endurance, proprioception, cardiovascular fitness and mental concentration are negatively affected by age (Burns et al, 1991). Nevertheless, skiing is enjoyed by the mature athlete, many of whom have enjoyed skiing and the mountains throughout their lives.

Burns et al (1991) have reviewed the effects of aging and how this may impact on the performance of mature athletes in skiing. Injuries that are common in alpine skiing were discussed in relation to the general population, with attention to certain injuries of particular relevance to the older skier. These were considered to be injuries such as disorders of the patellofemoral joint, and injuries secondary to osteopaenia such as fractures of the femoral neck, tibial plateau and proximal humerus. The general principles of rehabilitation with reference to the mature athlete were also discussed. Whilst maintenance of good health and physiological conditioning was recognised as a first step in avoiding injury, the authors also acknowledged that little has been published on the epidemiology, risk factors, treatment, avoidance and rehabilitation in this group of skiers and needs greater attention (Burns et al, 1991).

6.17 SKIING INJURIES IN PHYSICALLY DISABLED SKIERS

Snow skiing can be a very valuable experience for the physically handicapped in terms of physical rehabilitation, challenge and enjoyment. It can also be a wonderful and therapeutic social and recreational outlet that can promote enthusiasm and confidence. An expression among the physically disabled in America "Kick the handicap - Learn to ski" reinforces this. Skiing as a sport is growing in popularity among the disabled. Equipment

has improved, ski schools offer specialised and often individual instruction, and resorts and lift companies are more accepting and encouraging of disabled skiers (Krag and Messner, 1982; Laswowski and Murtaugh, 1992).

The ski equipment used by disabled skiers varies and depends on their disability. Equipment includes (Krag and Messner, 1982):

- three-track skiing for a unilateral amputee skier (one ski and two outriggers that consist of a forearm crutch with a single foot long ski tip attached to the end)
- use of a prosthesis for a below knee amputee, providing the prosthesis is a very good fit
- special adaptive equipment in skis, eg a 'ski bra' to prevent the tips from crossing, or canting wedges between the sole of the boot and the ski as developed for skiers with cerebral palsy
- ski-sleds, mono-skis or sit-skis may be used by paralysed skiers who would otherwise require wheelchairs.

A number of organisations in the United States of America are involved in the organisation and promotion of skiing for the physically disabled. Some have a special interest in certain medical diagnostic groups such as people with cerebral palsy, or the visually or hearing impaired, and others are more broadly based. Major ski events for the disabled are held at regional, national and international level, and the first Winter Olympic Games for the Disabled was held in Canada in 1976. Skiing instruction programs for the disabled have developed, sometimes as part of a rehabilitation program. Certain ski resorts, such as the Winter Park Ski Area in Colorado, have taken a special interest in developing, assisting and instructing disabled skiers (Krag and Messner, 1982).

Disabled skiers need a dry-land therapy program and appropriate physical conditioning program before embarking on a vigorous sport such as alpine skiing. The benefits of skiing have been considered to outweigh the injury potential (Krag and Messner, 1982).

A review of a four year period from 1985-9, compared the injury rates of disabled skiers, who were participating in a disabled skiing instruction program at major Colorado resort in the US, with the injury rate of general able-bodied skiers (Laswowski and Murtaugh, 1992). Over 45 different disabilities were represented in this program including amputation, hemiplegia, vision and hearing impairment, spinal cord injuries, multiple sclerosis and muscular dystrophy and 240 injuries were reviewed. The injury rate of 3.7 per 1000 skier visits for disabled skiers was not significantly different to that of 3.5 per 1000 skier visits for the able-bodied skiers. The types of injuries sustained tended to differ, however, and disabled skiers appeared to have fewer fractures and more abrasions and bruises. The location of injuries sustained was not significantly different between the groups, with the bulk of injuries occurring in the lower extremity (55-57%) and particularly the knee (Laswowski and Murtaugh, 1992). Unfortunately, the injury rates for disabled skiers with different disabilities were not reported separately in this study.

A similar review reported on 27 injuries that occurred over a 3 year period from 1986-9 in a Californian ski resort (Laswowski and Murtaugh, 1992). Over half of the disabled skier injuries in this study involved the head and neck region. The vast majority were minor and did not require medical attention. Most were bruises.

A safety concern for sit-skiers and mono-skiers (the ski equipment used by a person who requires the use of a wheel chair) has been the fear of injury during chair lift loading and unloading, the achievement of which requires two lifters. Injury statistics relating to disabled skier use of lift services was collected at Breckenridge, Colorado over a 3 year period from 1986-9. Chair lift rides for sit-skiers or mono-skiers were considered. In over 5000 chair lift rides to these skiers, more than 96% resulted in 'clean' loads and unloads, (ie no problems in the process). No injury occurred in the less than 4% where there was difficulty with the loading or unloading (Laswowski and Murtaugh, 1992).

Laswowski and Murtaugh (1992) recognised that major limitations of their study lay in inconsistencies in methods of data collection and reporting used by the disabled-skiing programs, and the resorts themselves, and that comparisons with the able-bodied skiers were also limited. They advocated prospective studies with data collection on incidence, location, and severity of injury and type of disability. They also recommended collection of data on the experience of skiers in the able-bodied skier and disabled skier populations, and comparisons between them. They recommended that the study design should also integrate a method of tracking the increasing population of disabled skiers in terms of skier visits and injuries sustained.

The Australian Disabled Skiers Federation is involved in a number of initiatives to assist disabled persons in becoming involved in the sport, and in the instruction of disabled skiers. Clinics for instructors to qualify them for teaching the disabled are conducted at all resorts throughout the season. About 350 disabled skiers are registered with the Federation. This does not include all skiers who have taken advantage of the facilities and support the Federation offers. About 2000 more disabled skiers are assisted through the accommodation at the ski lodge at Jindabyne, in the provision of equipment or the organisation of lessons. Once initiated into the sport, the reliance of disabled skiers, on family or friends for further support is encouraged.

7. SUMMARY AND CONCLUSIONS

Skiing is a popular sport in which there is a broad range of ages and standards among skiers, as well as skiers with various types of disability. According to the Alpine Resorts Commission, 10-12% of the population participates in skiing. The true level of 'real' skiers is likely to be closer to 5%, with an annual growth rate of 1.5%. Alpine skiers account for the majority (75%) of participants in alpine sports.

The main sources of skiing injury data in Victoria and Australia in general are those collected by the Ski Patrol. On the basis of Victorian Ski Patrol records presented annually at the annual Alpine Safety Conference, injury rates are estimated to be between 1.5 and 3.9 injuries per 1000 visitor days, and thus are comparable to the international mean of 3.65 per 1000 skier days. The rates of some injuries have changed over time and have been influenced by a number of factors including equipment design. There is nonetheless room for improvement in injury prevention, building on the initiatives already undertaken by skiing organisations and individuals.

The objective of this review was to determine the extent to which countermeasures for preventing injuries in the popular sport of alpine skiing have been evaluated. In particular, the results of these evaluations and the level of supporting evidence were considered. Finally, recommendations for further action in injury prevention research and practice were given.

The review highlights areas that need more formal evaluation, those that warrant more immediate attention and action and those in which recommendations for progress in injury reduction could be made now on the basis of existing evidence.

The sources of information used to compile this critical review were Medline, Sport Discus, conference/proceedings scan and NEXUS, discussions with local researchers and sporting organisations, Internet injury list postings, Standards Australia and CD-ROM world-wide standards index 1995/96 issue, presentations at the 1995 Alpine Safety Conference in Melbourne, and the Victorian SnowSafe booklet and video (1995) as well as consultation with experts in the field such as the Ski Patrol Association and key stakeholders. The literature review was restricted to articles in the English language available in Australian libraries, but where possible has focused on controlled trials.

Measures to prevent or control injury, otherwise known as countermeasures, can be targeted toward primary (pre-event), secondary (event) and tertiary (post-event) prevention in the chain of events leading to injury. Key injury countermeasures in alpine skiing include: pre-season conditioning programs, ski-bindings and their timely release, professional adjustment of ski-bindings and the use of mechanical testing devices to undertake this, ski boot design, the design of ski pole handles, helmets for children (and adults), ski patrollers and ski safety and rescue programs, skier education, speed and collision control on the slopes, identification and mitigation of hazards, increased ability and ski lessons, adequate clothing and eyewear and sun protection, adequate nutrition and limited alcohol intake, safe resort areas and safe lifting equipment.

For each countermeasure, the epidemiological basis and rationale for its use in injury prevention has been presented. A critical review of the evidence for its effectiveness in the prevention of skiing injuries and recommendations for further countermeasure research and development have also been provided.

A tabular summary presentation was developed to visually demonstrate the strengths of the evidence provided by various studies. The column headings relate to categories of evidence, and give an indication of the strength of that evidence. Anecdotal evidence or informed opinion is considered to be the weakest of the evidence available. Whilst not discounting the value of informed opinion, evidence from biomechanical studies, testing of equipment, or data-based studies, carries greater scientific weight. Stronger still is evidence gained from controlled evaluations conducted in the field. Finally, evidence of consumer opinion or acceptance is important in the implementation and institutionalisation of injury countermeasures.

Taken together, the tables clearly demonstrate that the weight of evidence is generally based on a combination of epidemiological studies, biomechanical evidence or testing of equipment, and informed opinion or anecdotal evidence. Very little evidence is based on controlled trials or the actual evaluation of countermeasures 'in the field'. Similarly, very little research has assessed consumer opinion. No economic evaluations of skiing injury countermeasures or studies of the cost of skiing injuries were identified.

The most evaluated countermeasures are ski bindings and ski pole handles. Properly adjusted ski bindings have the potential for a 3.5 times reduction in lower extremity injuries, particularly knee injuries. The design of ski pole handle needs innovation and attention. On the basis of the studies reviewed, no ski pole handle design eliminates the risk of injury. The weight of evidence did not strongly suggest that any particular handle design or method of holding the strap has a major influence on the likelihood of injury. Neither did it suggest that improved handle design had the potential to make a major contribution to injury prevention. There were methodological problems with some of the studies and the results were not always clearly presented. Innovation in the design, biomechanical testing and evaluation of this countermeasure does not appear to have been developed as much, or received as much, attention as other countermeasures such as the functional unit of the ski/binding/brake/boot system. The weight of evidence suggests that current bindings do not fully address the requirement for a multi-directional release mechanism that can to reduce the risk of lower limb injuries, and knee injuries in particular. Further technical developments and innovations are required. The optimal adjustment of bindings using a testing device, particularly by professionals, has been shown to be associated with a reduced risk of lower extremity injury.

Of concern is the generally poorer standard of children's equipment, ski bindings and their adjustment. The adjustment of bindings that are in use has been shown to be inadequate in overseas studies, especially in the case of children's bindings. Adjustment by the binding scale on the binding itself is not likely to be accurate. For an accurate adjustment, use of a testing device by adequately trained personnel is essential and should be standardised and done regularly. There is also room for improvement in the field of international standards.

Opportunities were identified for further countermeasure research and development on multi-directional release bindings, further case control studies on the effectiveness of binding adjustment in injury reduction, Australian studies of the adequacy of binding adjustment by skiers (children and adults), increased attention to the standard and adjustment of children's boots and bindings, the institution of regulations and standards for the training of personnel in ski shops and ski hire outlets on the use of mechanical testing devices, skier education on binding release and adequate adjustment, and the testing of various forms of skier education.

Improved ski glove design and falling techniques may also have a role in preventing upper extremity, particularly thumb, injuries. Newer types of handle design may have the potential for reducing the rate of associated thumb injuries. However, their evaluation in controlled trials or their usage by skiers in the epidemiological trials has not been sufficient to be clear on their potential for injury prevention. Opportunities for further countermeasure research and development include further research into the design of ski pole handles, ski straps and ski gloves and controlled evaluations of ski pole handle design in the field; assessment of falling techniques and consideration of what is taught by the ski school in relation to this; and specific advice, or training for doctors in and around ski field areas on the examination, management and rehabilitation of thumb and shoulder injuries.

There has been little formal evaluation of boot design as a countermeasure in injury prevention. Available studies relate to boot stiffness characteristics, pain threshold, and some differences in the requirements of males and females. The weight of evidence is centred on informed opinion. Boot characteristics, such as individualised fit and comfort, temperature isolation, and lack of pressure areas are obviously important and logically help prevent thermal or mechanical injury. The role of the transmission of forces in binding release has not been well investigated, as is the role of the boot in the prevention of ligamentous knee injuries. Consideration of boot characteristics in association with choice of the ski/binding unit has been recommended. The standard of boots also needs to be considered.

Opportunities were identified for further countermeasure research and development including boot design that improves comfort and prevents lower leg and knee injuries, attention to the design and standard of children's ski boots; and consumer education about ski boot design and function.

Technological developments in ski equipment, standardisation in the professional testing of ski bindings, and the optimal adjustment of ski bindings are recommendations arising from this review. Research on the attitudes, knowledge and behaviours of skiers regarding the professional adjustment of bindings is another important area in relation to the promotion of preventive measures and this has been less extensively researched. One Dutch pilot study evaluated the various facets of a skier education campaign that aimed to increase the rate of professional binding adjustment by skiers. The findings were considered too inconclusive to serve as a basis for a national campaign. Victoria has a safety campaign through SnowSafe that includes safety booklets and a video, and has been revised and updated but not formally evaluated.

With few formal trials, gaps in current knowledge exist in relation to the specific determinants of desirable or undesirable behaviour with respect to skiing injuries. Epidemiological studies followed by research on the determinants of behaviour were recommended.

Opportunities were identified for further countermeasure research and development including a study of the attitudes, knowledge and behaviour of Australian skiers in relation to risk factors associated with skiing, as a basis for educational and injury prevention programs; the identification of injury prevention countermeasures successfully promoted and evaluated in other sports, that may be relevant to skiing; and the further promotion of injury prevention countermeasures among Australian skiers.

Skiing is a physically demanding sport and expert and informed opinion suggests that poor physical condition, inadequate warm-up and fatigue may leave the skier at risk of injury.

Risk factors identified in epidemiological studies of skiing injuries include low ability and skill level. The countermeasures advocated to address these risk factors are pre-season conditioning programs and ski lessons. Common sense dictates that these countermeasures should not be discouraged, but their effectiveness has not been formally evaluated in controlled studies. More research and evaluation is needed to determine their effectiveness in decreasing the prevalence of musculoskeletal injury in skiing. In conducting such studies consideration needs to be given to whether the general recreational skiing population will accept the requirements of a rigorous training program.

The content of ski lessons, for example instruction in safety measures and falling techniques, or recommendations by instructors with respect to binding adjustment has not been the subject of consideration or evaluation in studies.

Opportunities were identified for further countermeasure development and research into the effectiveness of conditioning programs on the prevention of injuries; more rigorous evaluation of the impact and health outcomes of the Australian Physiotherapy Association's 'Get Fit to Ski with Physiotherapy' program; the standardisation of epidemiological data collection and reporting in relation to categories of skiing ability and history of ski lessons, in future studies; controlled studies and evaluation of the effectiveness of ski lessons as a countermeasure to reduce injury; and a review of the content of ski lessons with respect to skiing safety.

Skiing at high speeds and collisions with the skiers or with natural or man-made objects, have been identified as risk factors for serious injuries. Whilst many of the hazards of skiing will never be completely removed from the sport, and to do so may detract from the aesthetic beauty of the skiing in the mountains or the appeal of skiing as a vigorous adventurous sport, a balance is required. Speed control programs and the identification and mitigation of hazards are countermeasures designed to address these risk factors. These countermeasures have been evaluated to a limited extent, but more rigorous evaluation is required.

Opportunities were identified for further countermeasure research and development including continuation of skier education programs that promote safe skiing, identification of the most effective education methods; consideration of more targeted approaches to education; continued support for the promotion of speed control programs by ski patrollers; incorporation of countermeasure evaluations into routine ski patrol processes; routine monitoring with action as required for the reduction of injuries associated with lifting and resort equipment; standardisation of policies and methods for hazard identification and mitigation (if this is not already the case in Australian resorts); pilot testing of the calculation of injury severity scores and corrected injury severity scores for evaluating and monitoring slopes and resorts; and more formal evaluation of the effectiveness of hazard identification and mitigation in injury reduction.

Head, spinal and nervous system injuries are a concern in many sports including skiing. Expert and informed opinion suggests that properly designed protective headgear should help protect against head injuries. The use of such headgear may be appropriate to all skiers or more so for certain groups of recreational skiers, such as children. As a countermeasure for injury prevention in skiing, the effectiveness of protective headgear has not been formally evaluated. Current helmet design may interfere with vision, hearing and the provision of important cues to skiers increasing the risk of collisions. Cost, comfort, colour and design are features that may influence consumer acceptability. Other risk

factors such as speed, environmental hazards and skier behaviour also need to be considered in any strategy or program to reduce head or spinal injuries.

Opportunities were identified for further countermeasure research and development including into the further development and improved design of protective headgear; continued development of generic protective headgear that is adaptable to different sports; research into consumer opinion/acceptability of protective headgear; controlled trials or formal evaluation of the effectiveness of protective headgear in injury reduction; and the development of international standards for protective headgear.

There has been controversy about alcohol use and downhill skiing that most recently has surrounded the relationship between injury risk and alcohol use. The level of alcohol consumption among Australian skiers has not been studied, and the evidence for the contribution of alcohol use during or after skiing to the risk of injury is not conclusive. Alcohol consumption can contribute to hypothermia. It seems prudent to continue to advise skiers not to consume alcohol during skiing or if driving or intending to drive, and be guided by daily alcohol consumption guidelines recommended by health authorities. There is generally more consistent evidence regarding the benefits of nutritional intake during and after skiing.

Opportunities for further countermeasure research and development include reinforcement of the need for adequate nutrition and carbohydrate replenishment during and after skiing; studies on the alcohol consumption patterns of Australian skiers; and controlled studies on the relationship between skiing injury rates and alcohol consumption.

Clothing, eyewear and sun screen serve several purposes in alpine conditions, including protection from a variety of weather conditions such as snow, sleet or rain, high winds, poor visibility, brilliantly sunny days and strong reflective glare.

Opportunities for further countermeasure research and development include continued improvements in the materials for skiing garments and eyewear; clothing with higher coefficients of friction; continued reinforcement of the essential and protective aspects of clothing, eyewear and sun screen to skiers; and a review of the standard of available children's clothing and eyewear.

Standards Australia has emphasised the need for relevant and technically competent Australian standards. Standards Australia has a policy of adopting an international standard wherever an appropriate one is available. In developing new standards, a genuine need and community or interest group support needs to be demonstrated. Currently there are no Australian Standards for skiing equipment or the training of ski shop personnel. Opportunities for further countermeasure development and research include a review of Victoria's or Australia's policy regarding skiing equipment and requirements in relation to equipment standards, training and standards for ski shop personnel, ski binding fitting and adjustment in retail and hire outlets, and the use of test devices for binding adjustment.

The Ski Patrol Association (among other organisations) plays a key role in skiing education, safety and ski rescue in the mountains. The Ski Patrol Association also collects data through their 'Accident Report Form' and generally reviews performance at the end of the ski season. Data is not collected in the same format at all Victorian resorts, however, nor is it consistent with that of NSW resorts.

The standardisation of data collection across all Australian resorts would provide an improved data base for research, statistical comparisons, surveillance, the monitoring of injury trends and evaluation of the effectiveness of interventions or injury control programs. Injuries and injury prevention in subgroups of the skiing population such as children, various categories of disabled skiers, mature age skiers and needs more attention in the future. An 'Alpine Sports Injury Report Form' for data collection was developed as an outcome of this review.

Opportunities for further countermeasure development and research include the review of the incident/injury report forms used by ski patrollers to maximise the use of information for injury research and monitoring; consideration of methods for the collection of injury severity data and the potential for standardisation of this; standardisation of data collection by ski patrollers and all Australian ski resorts; standardisation of the age groups used for statistical comparisons in the analysis and reporting of injury data; development of injury surveillance programs in skiing; continued support for the Ski Patrol Association; integration of the Global Positioning System into search and rescue missions and the availability of appropriate equipment; and ongoing promotion of safe driving in the mountains.

Skiing is a wonderful sport that can be enjoyed by a wide variety of age groups and abilities. As a sport, skiing is growing in popularity and developing, but has a need for more controlled research on injury prevention. This review recognises the initiatives already undertaken by individuals and ski organisations, the available research and its findings and limitations, the improvements that can be made, and the opportunities for further research into and development of injury countermeasures. In doing so, this review provides a basis for further action in injury prevention research and practice in the sport of alpine skiing.

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APPENDIX 1

SUMMARY OF THE STUDIES EVALUATING SKI POLE HANDLE DESIGN AND METHOD OF HOLDING

| Anecdotal/Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Article reference |
|---|---|---|------------------------------|
| <p>Training skiers to get rid of ski poles in a fall may help reduce thumb injuries.</p> | <p>The authors viewed recordings of falls from World Cup races. Racers retained ski poles in hand during entire fall, but moment of impact of hand with snow was not able to be visualised.</p> | <p>A prospective survey of all thumb injuries presenting to emergency clinics connected to several Swedish ski areas. 126 cases were analysed for design of ski pole handle ("ordinary", handle with broad plate on top, "sabre" handle without a strap) and the way in which skier gripped the handle (3 ways). Controls (1619) were randomly selected from lift queues. Chi-square, $P < 0.001$ for significance.</p> | <p>Engkvist et al (1982)</p> |
| <p>Results: No type of ski pole design included in this study eliminates injury. No significant differences were detected when the type of handle and method of grip were compared, or when only the methods of grip were compared (so investigators concluded that there was no benefit in removing the strap from the handle). Significant difference were detected when handle design alone was compared, with skiers using handles with a broad plate on top having a higher rate of injury. However, this handle design is supposed to reduce the risk of more serious perforation injuries, so it is not justified to advise skiers against using this type of handle.</p> | | | |

| Anecdotal/Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Article reference |
|---|--|--|---------------------|
| | | <p>A prospective survey of all injured skiers presenting to the clinic at Sugarbush North, Vermont in 1972/3 to 1977/8 seasons: 1711 injuries, 998 randomly selected skiers as controls (11,000 lift queue skiers surveyed re sex, age, ability). A separate retrospective survey of 408 skiers found in the base lodge on one weekend and week day were surveyed regarding a history of thumb injuries, ski pole type and grip at time of injury.</p> | Carr et al (1981) |
| <p>Results: Of the 408 skiers in the retrospective survey, 23% had injured their thumbs at least once skiing, with only 27% of these actually reporting their injury. Amongst this groups of 408 skiers, 329 (81%) had straps on their ski poles and 19 % did not have straps on their ski poles. The number of skiers (and %) surveyed who used the different methods of holding the strap were: 19 (5%) kept hands outside straps, 98 (24%) went straight through straps and 212 (52%) went up and through the strap. The percentage of skiers receiving thumb injuries according to the various grip types were: outside straps (5%), straight through (21%), up through and down (25%) and "new sabre grip" (27%). (Note: this does not add up to 100% but no further information was available). There was no difference in rate of thumb injury in those using sabre grip handles. It was also noted that only 5% of the skiers who gripped their poles outside the strap had acquired a thumb injury.</p> | | | |
| | <p>The mechanism of thumb injuries and the potential involvement of the ski pole handle design in this was considered from an ergonomic perspective.</p> | <p>A prospective French study of 119 cases of thumb injuries presenting to ski resort medical centres was used to correlate the injuries with skier's ability, ski poles used, and whether they had "safety clips" to release the strap upon application of a certain force, and the mechanism of injury. The study attempted to separate the contribution from the handle and from the strap to the injury mechanism.</p> | Ledoux et al (1989) |
| <p>Results: Alone, or in combination with a prominent upper plate on the ski pole handle, the strap appeared to contribute to about half the injuries in leisure skiers, and could be dispensed with. Ski pole safety clips were inefficient and pole handles that surrounded the thumb were considered dangerous, as were some parts of existing pole handles. During a fall the thumb must be prevented from being ejected with the thumb abducted. For skiers who wish for a strap (eg habit or fear of losing the pole) the straps could be equipped with adequately "security clips" to allow the strap to open during a fall. The rationale is that the clip would substitute for the UCL MPJ of the thumb as the weak point. To be effective, improvements in the design and position have to be made on what is available to date. Competitive skiers are still likely to need straps.</p> | | | |

| Anecdotal/Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Article reference |
|--|---|--|----------------------|
| <p>Ski poles with a bow in the frontal direction should theoretically prevent the catching of the thumb in the snow during a fall, and thus reduce the risk of "skier's thumb" injuries.</p> | | <p>A prospective 2 year Dutch study of 1984/85 and 1985/86 seasons following a pilot in 1982/83. Participants were skiers who responded to local press/radio releases, and completed data on age, ability etc. A randomly selected group of 160 skiers were supplied with special ski poles with a bow in the frontal direction. All skiers returned information on reply paid post cards for up to 10 skiing days. For each skiing day, skiers reported on the skiing area, the kind of day (W/E, day trip, holiday), hours on slope, number of falls, binding releases during falls, the nature of any injuries. Prizes provided an incentive.</p> | <p>Hauser (1989)</p> |
| <p>Results: Results were based on 18,000 skier days. Skier's thumb is the most common ski injury today. Of all skiers, 3.7% reported a "skier's thumb" injury corresponding to a risk of 1.3 per 1000 skier days. 2.8% of the group with special bow-grip ski poles versus 4% of skiers with normal poles reported this type of thumb injury.</p> | | | |

SUMMARY OF THE STUDIES EVALUATING SKI GLOVE DESIGN

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|--|---|--|---|
| <p>A variety of ski poles have been designed or different methods of holding them advocated to ensure the released ski pole will fall from the hand in a fall. The design of a ski glove may help this.</p> | <p>A ski glove which incorporates a strong web between thumb and index finger has been designed which prevents extreme abduction of the thumb. There is also a band between the level of the interphalangeal joint of the thumb and the proximal interphalangeal joint of the little finger. The glove is designed so that the band is snapped tight and the ski pole is ejected when the wrist and fingers are reflexly extended in a fall.</p> | <p>A prospective study of patients presenting to Queen's Medical Centre, Nottingham over 12 months from April 1982-83 with skiing related thumb injuries re history of mechanism of injury and confirmed diagnosis. It was not clearly stated whether all skiers had been injured on dry ski slopes or real snow. A trial of the glove on the local hill was to be undertaken, but the method proposed for this was not specified</p> | <p>The authors acknowledge it's not high in the fashion stakes but the glove does not restrict hand function</p> | <p>Fairclough and Mintowt-Czyz (1986)</p> |
| <p>Results: The categories of the 28 ski-related thumb injuries in the prospective study were 17 cases of isolated injury to the UCL MCP joint, 6 cases of fractured base 1st metacarpal, 2 cases of fractured proximal phalanx, 1 case of incomplete rupture of radial collateral ligament and 2 cases of dislocation of 1st MCP joint. Of the 17 cases of UCL MCP joint injuries, 13 occurred when ski pole handle driven into 1st web space and 4 caught in dry matting of the ski slope.</p> | | | | |

APPENDIX 3

SUMMARY OF THE STUDIES EVALUATING SKI BINDINGS AND BINDING RELEASE

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|---|--|--------------------------------|---------------------|
| | | <p>Injured cases and controls were selected from the records of a Dutch ski insurance company and surveyed by mail for injury (selected on severity), self reported equipment use, binding adjustment and confounding factors including age, gender, self-reported ability, characteristics of skis and bindings, knowledge. Results analysed by stratification and logistic regression. Response rate >80%: 572 skiers (with 929 injuries) and 576 controls.</p> | | Bouter et al (1989) |
| <p>Results: Non-release of both bindings directly before an injury was associated with a higher risk for lower extremity (LE) injury (OR = 3.3). For release of one binding only the risk of LE injury was OR=2.3. Among LE injuries, the proportion of non-release was highest for knee injuries. No association between the time of adjustment or the method of adjustment was detected. Adjustment in a ski shop in the ski area (rather than elsewhere) and use of rented or borrowed skis were associated with a higher risk of injury. There was no association between the type of ski and age of the ski or bindings and injury risk. Inadequate knowledge of the skiing equipment was associated with an elevated general injury risk and was more strongly associated with a risk for LE injury. The hypothesis that binding release was less frequent prior to LE injury compared to non-LE injury appeared to be confirmed, but this needs to be interpreted with caution because skiers who were injured may have assumed their bindings did not release. LE injury can also occur if bindings do release prior to injury. Inadvertent release may predispose to a non-LE injury (a higher percentage of release was reported in that group). Some indirect evidence of linking prevention with the use of a test device was that among this group of LE injured skiers, release of two bindings was reported directly before injury by 31%. For professional adjustment with only the information supplied by the skier (and no test device), release of both bindings occurred in 26% of LE injured skiers. For adjustment without information (or test device) both bindings released in only 11% of LE injured skiers. The reason for increased risk association with rented or borrowed equipment, which could be because equipment was much used, low quality or poorly adjusted, was not clarified by the study or the reasons for the implications of decreased knowledge. Two-thirds of skiers in the study reported recent binding adjustment and half of the study population reported that the proper method was followed. The crucial question as to whether intervention in the form of adequately adjusting the bindings can prevent LE equipment related injuries was not investigated in this study and the authors felt this warranted further investigation as did a clarification of the quality of binding adjustment across European countries.</p> | | | | |

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|--|--|----------------------------|---|--------------------------|
| <p>In the setting of heel release levels the height and stiffness of the boot need to be considered.</p> | <p>Bindings of the experimental group were tested professionally and corrected to IAS standard free of charge at a ski institute prior to the ski season. This was not offered to the control group.</p> | | <p>A prospective 2 year study of 1984-6 seasons following a pilot in 1982/83. Participants were skiers who responded to local press/radio releases, and completed data on age, ability etc. Skiers were then randomly assigned to an experimental group (460 skiers) who had their bindings tested and set properly and controls who did not (690 skiers). A total of 160 randomly selected skiers were supplied with special ski poles (reported under section relating to ski poles). All skiers returned information on reply paid post cards for up to 10 skiing days. For each skiing day skiers reported on the skiing area, the kind of day (W/E, day trip, holiday), hours on slope, number of falls, binding releases during falls. If injured, they were to state type of injury. An incentive was provided through prizes.</p> | <p>Hauser (1989)</p> |

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|---|---------------------|--------------------------------|-------------------|
| <p>Results: Results were based on 18,000 skier days. The frequency of faults in the ski boot/binding system of experimental group before properly adjusted were: loosen binding screws (39%), sole holders too low (39%), pressure to the front of the heel element too high/low (37%), binding setting: deviation > +/- 20% (50%). The heel element generally had too low a release value, particularly in males (which would predispose to inadvertent release) and toe element generally too high a release value particularly in females. Even in very active skiers, 95% of all bindings tested had at least one fault and the average was 3.4 faults per binding unit. In the experimental group 81 (17.6%) and in control group 169 (24.5%) of skiers reported one or more injury events and the difference was statistically significant. The experimental group had 89.5 inadvertent binding releases per 1000 skier's days and the control group had 75.4 per 1000 skier's days, and the difference was significant. At 0.7 LEER injuries per 1000 falls, the experimental group injury rate was significantly lower than the control group rate at 2.4 per 1000 falls. The risk of LEER was about 3.5 fold lower with a properly adjusted binding compared to the average setting, and the difference was mainly due to a distinct reduction in knee injuries. Heel release levels were found in pre-testing to often be set too low and adjusters should pay attention to this as inadvertent release is undesirable. The researchers considered that the frequency of falls correlates more to skiing experience in years than to skiing ability as measured in "light, average, or superior".</p> | | | | |

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|---|---|--------------------------------|-----------------------------|
| <ul style="list-style-type: none"> analysis of a film of one skiing fall that resulted in a complete MCL and ACL rupture. | <ul style="list-style-type: none"> a mathematical model was used to determine boot top load which will disrupt the MCL vector analysis of a sprain of the deep MCL assessments of efficacy of a particular binding system using measured variables of unweighted and weighted release levels; derived parameters of ski-boot-binding coefficient; recommended release setting; fracture strength of bone and disruption strength of MCL. | <p>Prospective evaluation of all injuries (1141 in 1052 patients) in a northern Vermont ski area with randomly selected skiers as controls (number not stated) and comparisons made between 3 basic groups: controls, LEER, all other injuries. Knee injuries were classified as LEER or non-LEER injuries.</p> | | <p>Johnson et al (1979)</p> |
| <p>Results: Of total ski injuries, 21.6% were knee ligamentous injuries and 688 (60.3%) were LE injuries. Of the latter 499 (72.5%) were considered on the basis of questionnaire and clinical evaluation to be related to failure of the boot-binding system to release properly (LEER injuries). The mechanism of injury in the most common type of knee injury, sprain of the MCL, was external rotation with a valgus force. Bi-directional release bindings are not sensitive enough to configurations that can produce knee ligamentous sprains, and bindings that allow release in roll, shear and twist at the heel would be necessary to protect the knee</p> | | | | |

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|--|---|---------------------|---|---------------------------------|
| <p>A review of the historical developments of actively controlled electronic bindings prefaces the investigators description of the design and evaluation of the performance of the instrumentation system</p> | <p>Instrumentation system incorporates: dynamometer (measures 6 load components), electromechanical release mechanism, signal conditioning amplifiers, microcomputer controller, digital data-recorder, computer operating system software.</p> <p>This research system was field tested with 2 runs of each of the common type of turns through a 10 gate slalom course.</p> | | <p>The isolation plate used in this system results in a binding that is insensitive to ski flexure. If this affects ski performance it may not be acceptable to skiers. This was a research model in which the instrumentation system was carried in a backpack by the skier.</p> | <p>Macgregor et. al. (1985)</p> |
| <p>Results: The release mechanism was considered by the investigators to have performed well, and binding almost always released on command from the computer. On one run it did not release and on another it released mechanically without computer command. Laboratory testing showed that the release mechanism is intermittent in releasing under loading typical of skiing which was unacceptable. Data on moment loading histories and testing of new release algorithms was obtained but dynamometer did not allow resolution of boot forces. The investigators were looking at refining and making changes for a second generation binding system.</p> | | | | |

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|--|---------------------|--------------------------------|-------------------------|
| | <p>This research involved further development of a microcomputer controlled binding system for alpine skiing research concentrating on boot loading data and actively controlled release of skier's boot from the ski.</p> <p>The binding system was field tested over a slalom course using common types of ski turns. Loading data typical of recreational ski manoeuvres was collected.</p> | | | Wunderly et. al. (1988) |
| <p>Results: The researchers considered this research binding system to be a substantial step forward with improved operational reliability and performance. Some areas for further improvement were acknowledged. Recordings of force and moment time histories showed, within specific error boundaries, the representative loading during an actual downhill ski injuries amongst recreational skiers. It is a completely active device that can be programmed with release algorithms and will assist in further research into the dynamics of the skiing process as well as the mechanics of skiing injury. The researchers recognised that subjects were skilled skiers using controlled manoeuvres (and beginners were not likely to be able to exert edge control with the same proficiency) and snow and terrain conditions vary and can be more difficult than was used in this field test. The researchers have considered expanding the field testing with beginners and with skilled skiers on more difficult terrain.</p> | | | | |

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|--|---------------------|--------------------------------|--------------------------------|
| <p>The load causing heel release in a conventional binding release is an upwards force at the heel which correlates only weakly to bending moments developed at injury sites. The ability of release of the binding mechanism to protect against bending related injuries, eg "boot top" fractures, is thus impaired.</p> | <p>Testing of a ski binding prototype where heel release is activated by the anterior/posterior bending moment at the boot sole rather than the upwards force at the heel of the boot.</p> | | | <p>Caldwell et. al. (1993)</p> |
| <p>Results: The heel piece developed for the prototype is larger and heavier than allowed by design criteria, but the researchers consider it can be reduced to fulfil criteria. Vertical elasticity, longitudinal compliance and adjustability to different boot sole lengths are preserved. The concept was considered workable and the next step was the development of a skiable prototype. (The support of Tyrolia Corporation of Vienna, a major ski binding manufacturer, for the ongoing research program was acknowledged).</p> | | | | |

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|---|---------------------|--------------------------------|-----------------------------------|
| <p>Torsional loading plays a role in knee ligamentous injuries. A limitation of conventional bindings in protecting skier's knees is that release level of the binding toe piece is fixed (discounting dynamic effects) once it is adjusted. Muscles around the knee contract and relax during skiing and falling. A binding that can change it's release level in twist in response to the changing strength of the knee (as determined by the state of muscle contraction) will have greater ability to protect the knee.</p> | <p>Testing of a binding system prototype where the release level of the binding toe piece in twist is modulated according to the level of neural stimulation of one of the vastii muscles of the quadriceps group of muscles.</p> | | | <p>Eseltine & Hull (1993)</p> |
| <p>Results: Components of the system and the wire connection between the skier and the binding result in a binding that is both excessively large and heavy and is therefore not practical. The researchers consider that these barriers to practicality can be overcome by further development. (The support of Tyrolia Corporation of Vienna, a major ski binding manufacturer, for the ongoing research program was acknowledged).</p> | | | | |

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|-----------------------------|---|---------------------|--------------------------------|-----------------------|
| | <p>On-slope recordings of the lateral toe release torques of the bindings of 376 randomly selected alpine ski racers in Norway were made during 1982/3. Mounting of bindings was checked, and the deviation of binding release from that of the setting on the binding standard scale was calculated.</p> | | | Ekeland & Lund (1987) |

Results: Most of the bindings equipped with a standard scale were new, and 92% were 2 years old or less. Only 15% of the bindings had been tested in the current week. 77% of the bindings were correctly mounted. The front piece was mounted too low in 17% of the bindings with standard scale. The lateral toe release deviated significantly from the value indicated by the setting for several of the bindings tested. The mean deviation was 6%, but the dispersion was considerable. The deviation increased with age of the bindings, and in bindings with the front safe mounted too low. Deviation was least for the top models of each type of binding. 41% of the bindings released in accordance with the setting. The best test results were recorded in bindings one year old or less, those which had been adjusted by a binding mechanic, in models that were the top of the range and in those that were test-released the current week. The researchers recommended that alpine bindings should be well adjusted and maintained, and actuated (test-released) frequently to control release function.

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|--|---|---------------------|--------------------------------|--------------------|
| | <p>An instrumentation system measured complete force systems between the ski and the boot and rotations of the tibia relative to the femur across the knee during skiing field tests.</p> <p>Three field test series were conducted with 3 separate skiers. During these recordings were made and analysed.</p> | | | Kuo et. al. (1983) |
| <p>Results: The vertical force at the heel cannot control the bending moment at the tibia. The adjusted release setting of the binding can be exceeded and bending moments typical of the fracture strength of the tibia was exceeded in 50% of the test runs. Compression of the boot into the binding caused by ski flexure during skiing may influence the torsional release moment of the binding. This can be minimised through binding design. Vertical force at the heel is a poor predictor of the bending moment transmitted to the lower extremity during skiing, but vertical force under the toe is a better indicator. This may have practical application in binding release design. Skiers typically ski under potentially injury producing forces. The musculature provides additional support for the lower extremity, but the knee is the "weak link" in the lower extremity in skiing.</p> | | | | |

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|---|---------------------|--------------------------------|----------------------------------|
| <p>In skiing accidents skiers never fall perpendicularly upward, and strain on the lower extremity is often a combination of bending and torsional forces and moments in oblique directions. The retention force of ski bindings should be sufficient to prevent inadvertent release.</p> | <p>A material-testing machine (MTS) was used to test at quasistatic (low speed) release forces of six different type of bindings (1 lab prototype, 5 commercially available) in perpendicular and oblique planes. Settings were those for an advanced skier of body weight 70 kg & tibial condyle width 9 cm.</p> | | | <p>Lindjso et. al. (1983)</p> |
| <p>Results: The release resistance in planes at oblique angles to the normal should be lower than the perpendicular retention force so that the stress on the lower extremity and the resistance to release are as low as possible when it is required. Only certain multiple-release bindings with a spring-loaded moveable toe unit show these characteristics. In analysis of injury-preventing properties of a release binding, attention needs to be paid to release resistance in oblique planes.</p> | | | | |
| <p>A review of previous investigators' efforts concluded that to simultaneously satisfy the release and retention requirements of ski bindings, the dynamic system theory of human injury must be the foundation of future designs.</p> | <p>A definition of a biomechanical model for calculating tibial torsion based on measurements of torsion loading between the boot and the ski, and explores the contributions of both inertial and velocity-dependent torques to tibial loading. A new analogue controller design is presented.</p> | | | <p>Hull & Ramming (1980)</p> |
| <p>Results: (This is a complicated article that requires an understanding of mathematic and biomechanical modelling concepts to fully appreciate). Concluding remarks by the authors were that although the current biomechanical model has fixed parameters, achieving highest release accuracy may require a variable parameter model; the actively controlled binding system is designed to offer improved protection against tibial fracture but future binding systems must protect both ankles and knees as well. During falls the knee would tolerate significantly lower loading than during skiing and bindings designed to specifically prevent knee injuries may require stiffness biofeedback.</p> | | | | |

| Anecdotal /Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|--|---------------------|--------------------------------|------------------------|
| <p>Friction, or reduction of friction, is important in a number of aspects of ski equipment. Ski safety is dependent on the friction between the boot and the upper ski surface. Minimising the friction between the ski and the snow increases the speed of downhill skiing. The speed of cross-country skiing depends on an interaction between static friction when the ski is stationary relative to the snow and dynamic friction when the ski is gliding over the snow. The cross-country skier has to propel along level ground and uphill, and maximise speed downhill.</p> | <p>Methods of modifying the coefficients of friction and the influence of temperature on them are considered. Coefficient of friction between boot and ski with various boot shoe materials, conditions of the ski surface, temperature and wet and dry conditions was measured.</p> | | | <p>Outwater (1970)</p> |
| <p>Results: Reduction of friction between the ski boot and the ski is important in binding release. Teflon was the only satisfactory material for an antifriction pad on the ski beneath the surface of the ski boot. Use of a lubricant such as silicone grease would be impractical for skiers. With respect to friction between the skis and the snow, no material had the consistently low frictional resistance that teflon did under all conditions, and is the best ski surface from a frictional point of view. Unfortunately, teflon has too low a static coefficient to be useful. All waxes tested for static coefficients were adequate at temperatures below minus 7 degrees Celsius, but 2 were optimal regarding dynamic coefficients; at lower temperatures one of these was superior in this.</p> | | | | |

SUMMARY OF THE STUDIES EVALUATING CHILDREN’S SKI BINDINGS AND BINDING RELEASE

| Anecdotal/Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Article reference |
|--|---|---|---------------------------------|
| <p>Efforts in the development of new and better bindings have focused on adults, and marketing aspects have led to over simplification of children's bindings.</p> <p>The skeleton of children, compared to adults, has greater elasticity but lower strength. Fractures of the lower limb are predominantly caused by torsion.</p> | <p>The toe-piece mechanism of the binding was studied. Lateral release force was recorded. Maladjustments to heel mechanism and space between sole and slip plate were corrected and lateral release torque again recorded. The adjustment of the toe piece was compared to German and Swiss standards.</p> | <p>One hundred children were randomly selected from a lift queue in a Swedish ski resort and questioned on skiing ability and experience, age and ski equipment (especially type ownership, age and testing of equipment). Their skis with bindings and boots were tested in a room with outdoor temperature.</p> | <p>Ungerholm et. al. (1984)</p> |
| <p>Results: Fifty percent of the bindings were more than 5 years old (and likely second hand from older brothers/sisters). Very few had plate bindings and 42% had never tested their bindings. Fifty-five subjects had tested their bindings during that season, and 22 that week. The adjustment for 37 skiers was made by themselves or their parents and 25 by a ski shop. ANOVA found no relationship between deviation of the toe mechanism setting and age, or bindings adjustment by the skiers themselves and those adjusted in ski shops. In comparison to the German standard, 23 bindings were acceptable, 60 had too hard a setting and 17 bindings were locked. Only one binding gave a lateral toe release torque corresponding to the standard scale on the binding itself. Sixty percent did not have any slip space between the boot sole and the ski. After correction of the space, the lateral toe release torque decreased significantly. 42 bindings displayed a recentering force, but in all other bindings the boot became locked in position between the normal position and complete release. Overall, a very low percentage of bindings had an acceptable setting, lower than has been reported for adults; a large proportion locked in an unacceptable position and for 9 bindings a correct toe setting could not be made. 75% did not have a recentering force. Optimal functioning was also be hindered by a lack of slip space. The IAS (Swiss) system recommends lower settings and should be the system of choice.</p> | | | |

| Anecdotal/Informed opinion | Laboratory-based, biomechanical and equipment testing | Data-based evidence | Article reference |
|--|---|--|--|
| <p>Ski lessons should be the best way of rapidly increasing children's skiing ability.</p> | <p>The release force of the toe mechanism and heel mechanism were compared to IAS-80 (Swiss reference system) and to the scale on the binding itself.</p> | <p>A prospective survey comparing 31 children who sustained a lower extremity injury during downhill skiing is Lindvallen, Sweden with 503 controls randomly selected from lift queues during the 1982/3 season. They were questioned with respect to age, mechanism of injury and accident itself, skiing ability, equipment, binding adjustment etc. Binding function of 25 of the injured skiers and 139 of the controls was checked.</p> | <p>Ungerholm & Gustavsson (1985)</p> |
| <p>Results: There was no significant difference in ownership of equipment between the injured and control groups. In general, the release force of the toe mechanism in both groups deviated markedly from the IAS-80 reference system in both the injury group and control population, but the deviation was significantly higher in the injured group. The heel mechanism showed moderate deviation in both groups, more so in the injured group, although the difference was not significantly different. There was also a marked difference between the settings for the toe, but not heel, mechanisms on the binding scale and when measured release values were assessed using a testing machine. Again this difference was significantly higher in the injured group. The risk of sustaining an injury did not seem to be influenced by where, or by whom the bindings had been adjusted, and self testing of bindings did not seem to prevent binding-related injuries. A testing device is the most adequate method of testing binding function. The poor function of heel mechanisms may explain the high incidence of spiral fractures produced by torque in children.</p> | | | |

SUMMARY OF THE STUDIES EVALUATING SKI BOOT DESIGN

| Anecdotal/Informed opinion | Laboratory-based, biomechanical and equipment testing | Article reference |
|---|--|--------------------------------------|
| <p>The specifications for boot stiffness in forward lean need to recognise that the stiffness of the boot is a function of the skier (eg mass, strength) and that there are significant differences between men and women in maximum dorsiflexion.</p> | <p>A series of five cases with bending fractures were examined and their boots and bindings tested</p> | <p>Shelay & Ettlinger (1987)</p> |
| <p>Results: The release settings were consistent with those recommended, but during the incident leading to injury the bindings had failed to release. The boots allowed forward flexion greater than the 40-45° of the IAS 150 specification. Failure of the boot to act as a transmission device in transmitting the load from the skier to the binding may be a major factor in "boot top" fractures.</p> | | |
| | <p>Investigation of boot stiffness distribution in order to prevent boot-top fractures, with the intention of minimising the maximum bending moment or maximum stress on the tibia. Three tibial models were used.</p> | <p>Lyle & Hubbard (1991)</p> |
| <p>Results: The optimal boot width using the two-dimensional beam tibial model was 5.1 mm. The authors comment that this optimal boot width still seems rather small and intuitively such a boot "would be painful". On the basis of this study the authors conclude that the optimal boot design for prevention of boot-top fracture applies a force as high up toward the knee as possible to reduce the bending moment. It should be shaped as a band over a finite width only wide enough to reduce the effects of concentrated loading.</p> | | |
| <p>There is no problem with very tight boots as long as the maximum pressure does not affect anatomical structures in the long run.</p> | <p>Analysis of the pain threshold at 14 different locations on the lower leg in males and females aged 21-34 using a mechanical testing device.</p> | <p>Schaff et. al. (1991)</p> |
| <p>Results: The female group had a significantly lower pain threshold than the male group. Lowering the skin temperature more than 10°C resulted in a significantly higher pain threshold. Considerable variation among subjects meant that a maximum value tolerable in ski boots was unable to be given with a sufficient confidence interval. Requirements of females may be different to males.</p> | | |

| Anecdotal/Informed opinion | Laboratory-based, biomechanical and equipment testing | Article reference |
|--|--|------------------------------|
| <p>Skiers will use the optimal range of 0 to 30° forward flexion only if they feel no pain from the front of the boot shaft.</p> | <p>This study aimed to determine important parameters of the ski boot shaft, and measured pressure distribution at the front of the lower leg, the force at the heel, and the interactions between them in skiers. On slope testing was conducted, and related to learning ability. Three different representative ski boots were tested: high, medium and low shaft models.</p> | <p>Hauser et. al. (1985)</p> |
| <p>Results: Different boot shafts lead to completely different pressure distributions in the lower leg. At the same foot/leg angle, the force at the heel with boots of different shaft heights or stiffness varies widely. Pain thresholds in the lower limb vary between individuals and the pain threshold for females is lower than males. Skiers with boot shafts with a softer setting showed better learning results and better bending of the knee joint.</p> | | |

SUMMARY OF THE STUDIES EVALUATING SKIER BEHAVIOUR

| Anecdotal/Informed opinion | Laboratory-based, biomechanical and equipment testing | Article reference |
|---|--|---------------------------------------|
| <p>Authors cited 3 references re lack of consensus on the overall safety effect of ski lessons. Risk factors are often strongly associated and act together in causation of a ski injury. This presents difficulties in causal interpreting OR or EF.</p> <p>The next step is to study the determinants of skier behaviour and conduct a preventive trial in which behavioural change and reduction of injury can be investigated.</p> | <p>A 1984/5 study of Dutch skiers, which involved 572 skiers (cases) who filed an insurance claim for medical costs of a skiing injury of duration more than 1 day; and 576 uninjured skiers (controls) who filed claims for non medical reasons. The study considered the association of injury with behavioural risk factors such as ski lessons, binding adjustment, alcohol consumption and risk underestimation were cons. Odds ratios (OR) as well as an estimation of the etiologic fraction (EF) where appropriate was reported.</p> | <p>Bouter & Knipschild (1991)</p> |
| <p>Results: Beginners have twice the injury risk of intermediate or advanced skiers (OR=2.1, CI=1.5 to 2.9). Authors found no overall effect of ski lessons (OR=1.0, CI=0.8-1.4). The small group of beginners (9%) who refrain from taking lessons have a higher (2.5 times) risk compared to beginners who do take lessons, and contrasts unfavourably with intermediate or advanced skiers (2.1 x 2.5=5.3). EF=12%. One fifth (19%) of Dutch skiers prepare with a pre-season course of ski gymnastics, but no protective effect was identified (OR=1.1, CI=0.7 to 1.6). Binding adjustment is considered in another part of the matrix, but EF of completely avoiding the failure of the bindings to release during a fall would reduce the lower extremity injury by 22% in men and 39% in women. OR give the impression of a protective influence for alcohol consumption and average daily alcohol consumption during the holiday, but authors caution this is not causal and their impression is that it is neither a major risk factor, nor is it a protective factor. Skiers score relatively highly on the Sensation-Seeking-Scale especially on a subscale indicating a desire to engage in risky activity (but injured skiers scored less than non-injured skiers. It is proposed that underestimation of risk is the crucial factor (and EF of health education focused on this point = 35%). Caution that role of this is really not well studied or conclusive and needs further study before an education intervention is based on this. For putative behavioural risk factors better evidence exists for the contribution of inadequate binding adjustment and failures of beginners to take ski lessons and to a lesser extent underestimation of the actual risks.</p> | | |

SUMMARY OF THE STUDIES EVALUATING EDUCATIONAL CAMPAIGNS

| Laboratory-based, biomechanical and equipment testing | Controlled evaluations | Consumer attitudes/acceptance | Article reference |
|--|------------------------|---|-----------------------------|
| <p>Investigators referred to a 1974 article that the practice of skiers adjusting their own bindings "has proved to be incapable of improving the function of bindings" (52).</p> | | <p>A survey of 160 injured and non-injured skiers in Vermont. A behavioural intention model was basis for a questionnaire re skier's attitude toward his/her performance of ski safety and perception of social pressure for ski safety. The study looked at predictor variables in skiers with or without bindings adjusted professionally or by self over the preceding 6 months.</p> | <p>Rosen et. al. (1982)</p> |
| <p>Results: Injured and non injured skiers were not identified separately in the analysis. For the 160 skiers, the categories of whether or not they obtained a binding adjustment in the last 6 months were professional (yes 89, no 71); self (yes 31, no 129). Skiers who had obtained a professional binding adjustment were more likely to believe that professional binding adjustment prevents inadvertent release. They were also more likely to want to follow the experts advice about professional adjustment. Skiers who had adjusted their own bindings were more likely to believe that self-adjustment prevents injury and inadvertent release. Both groups of skiers believed that inadvertent release was undesirable. Skiers who did not adjust their own bindings believed that the experts were against self-adjustment of bindings. Binding adjustment was related to the combination of the skier's attitude about binding adjustment and their tendency to consider what others think should be done. In reference to the potential for promotion of professional binding adjustment as a preventive measure, the authors conclude that it may be important to provide skiers with more factual information about the relationship between release settings and ski accidents and that respected groups within the skiing community and industry should promote proper binding care even more rigorously than they presently do.</p> | | | |

| Laboratory-based, biomechanical and equipment testing | Controlled evaluations | Consumer attitudes/acceptance | Article reference |
|---|---|--|----------------------------------|
| | <p>A prospective randomised controlled health education intervention of 1288 people recruited at ski fairs. The message was "Have your bindings adjusted in a ski shop with the aid of a test device". Three conditions varied for the experimental groups: timing of delivery (1 or 3 weeks before ski vacation); medium of the education material (cassette or leaflet); approach of the message (fear-arousing or neutral). The control group received no information. Follow up was by telephone survey after receipt of the material and at end of ski season.</p> | <p>Respondents were actively sought and there was a good response to the survey. Behaviour was most affected by information with a high degree of fear. There was little difference between the media (cassette or leaflet), but it was better to give in advance (3 weeks rather than 1 week) before the skiing vacation.</p> | <p>Damoiseaux et. al. (1991)</p> |
| <p>Results: ANOVA was used to examine the effect of the three conditions (medium, moment, approach) on changes in attention, behaviour comprehension and intention. The cassette received a higher degree of attention than the leaflet, irrespective of timing or degree of fear. The level of comprehension was higher in the experimental groups than the control group. Information sent 3 weeks before departure and with a high degree of fear had the most effect on the level of comprehension. No differences were found for intention and behaviour between the control and experimental groups but there was among the experimental groups. Information sent shortly before departure and information with a low level of fear had the least effect on intention. Leaflets were recommended for practical reasons, and the message that was delivered in the medium was considered important. Behaviour was most affected by information with a high degree of fear, regardless of the timing and medium. The investigators acknowledge that before an intervention is implemented it should be established that the advice actually leads to the desired behaviour change. This study served as a prototype for a national campaign in the Netherlands, but there was no indication of whether the results of this study justified a large-scale intervention.</p> | | | |

APPENDIX 8

SUMMARY OF THE STUDIES EVALUATING THE ROLE OF PHYSICAL CONDITIONING

| Anecdotal/Informed opinion | Data-based evidence | Article reference |
|--|--|---|
| Inadequate preparation contributes to injury risk while skiing, and muscle and joint soreness and early fatigue can impair the enjoyment of a holiday. Each year physiotherapists see and treat many injuries incurred on the slopes. The Australian Physiotherapy Association program "Get Fit to Ski with Physiotherapy" developed as a preventative initiative that is specific for skiers and the demands skiing places on them. | Evaluation of the APA "Get Fit to Ski" program consisted of a survey of participants directly after the classes completion at the end of the program and at the end of the skiing season. | Australian Physiotherapy Association (1995) |
| <p>Results: 90% or more of respondents at the end of the 1989 season said that the classes had improved their standard of skiing, 91% of questionnaire respondents reported that they had reached their previous level quicker than usual, 93% reported less muscle soreness than usual after the first few days and 90% experience less fatigue while skiing compared to the previous season. 75% of those who responded to the survey completed the season without injury.</p> | | |
| Increasing ability, and thus lowering injury risk through ski lessons, or a course of ski gymnastics as preparation for skiing, are not based on sound empirical evidence. | A 1984/5 case control study among insured Dutch downhill skiers. Information was obtained via a postal questionnaire sent to 572 injured skiers and 576 skiers who claimed for non medical reasons. Skill was characterised in terms of ability, experience, number of falls, and exposure to formal instruction. Self reported physical condition and preparatory exercises were considered as variables. | Bouter et. al. (1989) |
| <p>Results: Self-reported beginners appeared to have a higher injury risk (OR 2.1, CI 1.5 to 2.9) compared to intermediate and advanced skiers. Among skiers with only 1 or 2 years experience ski lessons appeared to have a protective effect. No beneficial effect was demonstrated for training on an artificial ski run, ski gymnastics, a good physical condition or sports participation, although the researchers acknowledged that the results needed to be interpreted with caution at least in part because of variability of the data and difficulties in the validity of self reported data in a study of this kind.</p> | | |

**SUMMARY OF THE STUDIES EVALUATING THE
ROLE OF CLOTHING, INCLUDING PROTECTIVE
EYEWEAR**

| Anecdotal /Informed opinion | Biomechanical testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|--|---|---------------------|---|-----------------------|
| <p>The material thickness of ski gloves is often limited because of the restrictions on the diameter of ski gloves. The high surface area of ski gloves, in comparison to mittens, provides a challenge to limiting heat loss and maintaining comfort.</p> | <p>Study of a new technique of testing the thermal resistance of gloves using a flexible bladder shaped to simulate a hand. Heated vapour is generated and pressurises the bladder to a given pressure. An infra-red scanner is used to acquire a thermogram of the glove, and the thermal resistance of the glove can be calculated.</p> | | <p>Gloves allow greater dexterity than mittens, but a greater surface area for potential heat loss. Warmth and comfort are of great importance.</p> | <p>Roberts (1990)</p> |
| <p>Results: The advantage of this method is that it is easily adapted to various glove sizes. Thermal resistances can be compared. Thermal resistance of ski gloves is an important design characteristic of ski gloves.</p> | | | | |

| Anecdotal /Informed opinion | Biomechanical testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|-----------------------|---------------------|---|----------------------------------|
| <p>A layered system of clothing is recommended for recreational skiers. This does not meet the needs of professional ski instructors, for whom clothing must be suitable to worn uniformly and consistently, and with comfort, throughout the day, in all weather conditions and at various exertion levels.</p> | | | <p>A prototype design of ski clothing for ski instructors has been developed. The design is based on information on functions of the body, the basis for cold weather clothing, structure and functions of textiles, and results of a questionnaire survey of managers at 111 randomly selected ski resorts and individual male ski instructors at 44 North American resorts.</p> | <p>Laine & Hester (1989)</p> |
| <p>Results: A design was developed which considered the combination of fabrics, insulation, and design features required by the ski instructor to meet the requirements for protection, thermal comfort and function. The middle shell was crucial, and different materials were layered, and the number of layers specified, to correspond to different parts of the garment. The fabrics used in the middle shell provided properties of protection from the cold and precipitation and prevention of overheating, and these complemented the outer shell. The garment is designed to be aesthetically pleasing, functional and fashionable with attributes that do not exist in garments for recreational skiers.</p> | | | | |

| Anecdotal /Informed opinion | Biomechanical testing | Data-based evidence | Consumer attitudes /acceptance | Article reference |
|---|---|--|--------------------------------|-----------------------|
| <p>Generally little information available on skiing injuries involving eye wear. Primary function of sunglasses is to protect the eyes from ultraviolet and infrared rays and to improve visibility. Photochromatic lenses which change colour with variable lighting conditions may be important to improve visibility. Glass lenses have a higher optical quality and are more scratch resistant than plastic lenses. Frames should be smooth and strong.</p> | <p>ASTM specification for Eye Protective Devices (F659) passed in 1980 included sections on testing lens breaking strength.</p> | <p>History of eye injuries in skiing in United States presented in review of literature, National Electronic Injury Surveillance System records (NEISS) (1978 to 1984), National Ski Areas Association 3 year study, 11 year Vermont skiing injury study, telephone survey of 29 ski area medical clinics and hospitals.</p> | | <p>Piziali (1989)</p> |
| <p>Results: Of 66 NEISS entries with "skiing" and "eyes" most were related to contusions or abrasions from poles or skis, only 4 mentioned goggles or glasses, only 2 broken glasses or goggles which did not injure the eye itself. None required hospitalisation.</p> | | | | |

APPENDIX 10

SUMMARY OF THE STUDIES EVALUATING THE ROLE OF PROTECTIVE HEADGEAR

| Laboratory-based, biomechanical and equipment testing | Data-based evidence | Article reference |
|---|---|-------------------|
| Study of experimental impact mechanisms of human skull depressed fractures on 9 skulls with total of 38 dynamic tests (23 temporal, 15 frontal). | | Oh & Ruedi (1982) |
| <p>Results: An experimental tolerance threshold of about 1 to 2 kN for a depressed fracture in the temporal region (the energy that leads to fractures in this area is equal to an impact at about 16 km/h or a fall from a height of about 1 metre). In the frontal region the skull is 3 times as thick and in a test with 2.5-4.0 kN, a slightly depressed fracture was observed. The injuries and the force of the impact depend on the speed. Local application of force on the skull can lead to depressed fractures. In authors opinion, proper head protection gear should be mandatory for sports performed at more than 20 km/h, particularly for children and young people.</p> | | |
| | A retrospective survey of 18 patients with cervical spine injuries from skiing. | Oh (1984) |
| <p>Results: Of 18 cases, 7 were under 17 years and 13 were male. Twelve patients suffered from slight to severe head injury and one died. In the position assumed by skiers at high speed, a back extension would provide additional protection against the cervical spine. A safety helmet and prevention measures could reduce head and neck injuries.</p> | | |

SUMMARY OF THE STUDIES EVALUATING THE ROLE OF LIMITATION OF ALCOHOL INTAKE

| Anecdotal/Informed opinion | Data-based evidence | Article reference |
|--|---|---------------------------------------|
| | <p>This study involved interviews with 389 injured and 899 randomly selected non-injured adult skiers in relation to: demographics, skiing abilities and experiences, sensation and thrill seeking behaviour and interest, opinion on alcohol's effects on skiing performance and 24-hour drinking histories. The skier's blood alcohol concentration (BAC) was measured with a breath analyser.</p> | <p>Meyers et. al. (1996)</p> |
| <p>Results: Participation rates were 76% injured and 86% non-injured skiers. Six percent of all skiers had blood alcohol reading greater than zero. Among these skiers the median reading was low (1 ml/dl); the mean was 7 +/-5.7 ml/dl and the range was 1-24 ml/dl. A quarter of skiers report that they ever drink while skiing, and 34% reported alcohol use within 24 hours of the interviews. Males are more likely to drink and ski, and younger skiers were more likely to have drunk within 24 hours of the interview. Injured skiers are more likely to be female, more likely to be first-year skiers, less likely to report that they drink and ski, but more likely to report alcohol use in the 24 hours before the interview. The data suggested that drinking skiers may increase their risk of injury as a consequence of drinking that took place the day/night before they skied. The reason is unclear, but it may be related to a "hangover" effect on cognitive or motor performance. It may, however, be confounded by general late night behaviour and associated day-time fatigue</p> | | |
| <p>Risk factors are often strongly associated and act together in causation of a ski injury. This presents difficulties in causal interpretation of odds ratios (OR) or etiological fractions (EF). The next step is to study the determinants of skier behaviour and conduct a preventive trial in which behavioural change and reduction of injury can be investigated.</p> | <p>A 1984/5 study of Dutch skiers, which involved 572 skiers (cases) who filed an insurance claim for medical costs of a skiing injury of duration more than 1 day; and 576 uninjured skiers (controls) who filed claims for non medical reasons. The study considered the association of injury with behavioural risk factors such as ski lessons, binding adjustment, alcohol consumption and risk underestimation were cons. OR and an estimation of the EF where appropriate, was reported.</p> | <p>Bouter & Knipschild (1991)</p> |
| <p>Results: The injury odds ratio was adjusted for different levels of alcohol consumption (according to that consumed during breaks or on an average daily basis). These were less than unity (with confidence intervals that did not include unity) giving the impression of a protective influence for alcohol consumption during breaks and an average daily alcohol consumption of 5 standard glasses or more during the holiday. The researchers caution that this is not causal, and may be confounded by other factors. Their impression is that it is neither a major risk factor, nor is it a protective factor.</p> | | |

SUMMARY OF THE STUDIES EVALUATING THE ROLE OF SAFE LIFT EQUIPMENT

| Anecdotal/Informed opinion | Data-based evidence | Article reference |
|--|--|-------------------------------|
| <p>Information on, and training in, T-bar lift technique at ski school classes for beginners, intensified supervision of the lift tracks with a high preparedness for shutting the machines, a lower speed for non-manned lifts, safer alighting ramps which push skiers away from the lift track, better padding of the T-bars will help reduce injuries.</p> | <p>A report on T-bar related injuries. Of injuries over 3 seasons in Sälen, Sweden 168 (7.5%) were injuries from T-bar lifts that were sustained in the lift queues, during boarding or alighting, or during the lift rides.</p> | <p>Lindsjö et. al. (1985)</p> |
| <p>Results: At the resort where most of the injuries occurred, only 1 of the lifts was manned at the boarding station. Alighting is another opportunity for injuries to occur to both skiers who are alighting or those who haven't moved away and get hit by swinging T-bars.</p> | | |