Overview

The International Society for Skiing Safety was founded shortly after a 1974 meeting on skiing trauma and skiing safety organized by Professor Ejnar Eriksson in Riksgränsen, Sweden. The goal of this society was to bring together individuals of many disciplines to exchange information and present formal papers concerning the problem of snow skiing injuries. Since 1977, a ski trauma and skiing safety conference has been held every other year. Publications of the proceedings of the first two meetings were presented in a full length article format in a volume of *Orthopaedic Clinics of North America* in January of 1976, and in a book published by University Park Press in Baltimore in 1977 entitled *Skiing Safety II.* The third and fourth symposia proceedings were published as *Skiing Safety III* and *Skiing Safety IV* published by the Tchnisher Uberwachungs-Verein Bayern in Munich in 1982. The International Society of Skiing Safety was extremely pleased when it was able to join forces with ASTM as co-sponsors of the five most recent conferences. In 1983 the first co-sponsored meeting was held in Keystone, Colorado in May. In April 1985, it was held in Naeba, Japan, in May 1987 it was held in Chamonix, France; in May 1989 the meeting returned to the site of the origin of the International Society of Skiing Safety in Riksgränsen in northern Sweden. The Ninth International Symposium on Ski Trauma and Skiing Safety, which provided the publications for this text was held in Thredbo, Australia in June of 1991. Each of the five co-sponsored symposia have resulted in the publication of an STP. This text includes 24 peer reviewed articles that were presented at the 1991 symposia.

The conference in Thredbo was very representative of previous symposia with its main goal well realized by bringing together individuals from many disciplines including medicine, biomechanics, engineering, ski area management, ski patrol, epidemiology, ski area design, ski instruction, ski-equipment retail and many others who believe it is important to continue to strive for greater safety in skiing. At the Thredbo conference, 55 papers were presented by individuals from eleven countries. As is the usual process in establishing a Special Technical Publication from the proceedings of a meeting such as the Thredbo ISSS/ASTM meeting, the authors of all presentations were offered the opportunity to submit papers to undergo a peer-review process to assure that the papers accepted for final publication are of a high technical quality.

It is the purpose of this text to provide all readers with exposure to a concentrated body of material produced by experts in the field of skiing safety problems. Because of the interdisciplinary nature of the subjects presented in this text, the papers are divided into the five following categories: Alpine Skiing Epidemiology, Biomechanical and Physiological Aspects of Skiing, Ski Binding Topics, Skiing Safety and Other Closely Related Winter Sports Injury Topics. There is no doubt that this series of ISSS/ASTM Symposia continues to be the most substantial body of literature in this field in the world. We hope many who study this material find it stimulating and perhaps helpful in establishing their own efforts in advancing the knowledge that can further reduce risk of injury in skiing. We would urge those who are involved in research or who wish to become involved in research concerning the subject of skiing safety, to join us in the International Society of Skiing Safety and ASTM in attending future meetings of our two societies in their co-sponsorship of further Symposia on Ski Trauma and Skiing Safety. Individuals interested in participating in future symposia are requested to contact the editors or ASTM for information on how they may participate. At the present time plans are well underway for the Tenth International Symposium to be held in Kaprun, Austria in mid-May 1993.

During the last two decades, which corresponds roughly to the existence of the ISSS and the ASTM Committee on Snow Skiing, many changes have been noted in the sport of snow skiing and its unfortunate association with the production of injuries. There can be little doubt that through changes in the skiing equipment, ski instruction, snow making and snow grooming among a multitude of other variables, there have been many alterations in the incidence and type of injuries produced in skiing. Although there has been a general improvement in the overall injury rate, there has been an alarming increase in incidence of serious knee sprains. It is clear that lower leg and ankle injuries, which had been the most common anatomic areas to be injured, have been dramatically reduced. However, the knee injury is now the single most perplexing problem that continues to go unsolved. There can be little doubt that there is still need for improvement in the equipment used in skiing, but it has become apparent that the binding cannot be condemned as the device that is not functioning properly if knee ligament injury occurs. It is now understood that the boot and ski are intimately related to the series of events that lead to severe knee sprains. Those of us who have endeavored to identify the causes of severe knee injuries remain frustrated. It is very clear that the complex biomechanical mechanisms producing such injuries are still not fully understood and that in spite of the efforts presented in the past and in this STP, there is need for a great deal of further research to solve the remaining problems. Unfortunately, this is going to take the perseverance of those who are already involved in such efforts as well as the recruitment of many other individuals who are willing to join in this complex task.

Although there is little evidence that the incidence of catastrophic injuries that result in death or severe or permanent crippling have changed in recent years, the fact that they still occur also challenges us. It is unlikely that all injuries will be eliminated in a sport such as skiing where high speeds in potentially dangerous environments are commonly attained. The challenge to researchers, ski area management and equipment manufacturers among others, is to continue to seek the means of identifying problems that can be eliminated. As is so often the case in any endeavor where one delves into the details of the production of a problem, we often find that on evaluating a situation that we expose more questions than answers. This certainly does not give us an excuse to abandon our efforts with a feeling that the problem is so complex that there is no solution. As a group of individuals interested in skiing safety we must continue our efforts to find ways to solve the remaining problems.

Summary

Alpine Skiing Epidemiology

In this section of the text, six papers concerning further information about ski injury epidemiology are presented. These studies identify the changing pattern of injuries. The subject of ski injury epidemiology has been one of the most heavily investigated aspects of the subject of skiing safety. It is only through continued efforts such as these, where the changing incidence and patterns of injury are monitored, will we be able to identify whether attempts to improve the skiing injury situation are, in fact, being successful.

Johnson et al. have added another three-year experience to their now 18 years of monitoring a northern Vermont ski area in a classic epidemiologic observational study format known as a case-control study. In this endeavor, the authors attempt to as closely as possible to identify the population at risk and in this way be able to provide accurate information concerning the injury rates generated in a longitudinal study. They observed that the overall injury rate has continued to decrease over the 18 years of study and is now down by 48%. Lower leg injuries improved the most with an 83% reduction noted. Although the incidence

of knee ligament injuries did not change significantly, the incidence of severe knee sprains usually involving complete tears of the anterior cruciate ligament increased an alarming 209%. The incidence of upper body injuries has not changed significantly through the years with the exception of lacerations and thumb ulnar collateral ligament sprains, which have decreased. Although fractures in general are down in incidence, clavicular fractures were found to increase during the 18 years of this study by 176%.

Shealy in his expansion of previous efforts to evaluate a large group of ski areas in the United States based on ski patrol data has found that the overall injury rate has dropped by 20% between 1978 to 81 and 1988 to 90. The recent rate of injury was down to 2.7 injuries per thousand skier visits compared to 3.3 injuries per thousand skier visits 10 years before. The injury rates for male and female skier populations are essentially the same when controlled for ability level. However, females tend to have a lower ability scale than males, and thus were found to be more frequently injured. The rate of injury of beginner/novice skiers is about 10 times that of advanced and expert skiers.

In his study, Lamont evaluated skiing injuries at several ski areas in 1989 and 1990 in New Zealand. He noted the highest rate of injury at a ski area that had the highest incidence of beginner skiers. His observation was similar to Shealy's in that inexperienced female skiers were over represented in the group that sustained lower leg injuries. He was also concerned by the relatively high incidence of major knee ligament trauma in their study that indicates that phenomenon of severe knee injuries is world-wide.

The next two articles by Ekeland et al. and Giddings et al. evaluate the problem of injuries sustained by children in Norway and Australia. Ekeland's work revealed that skiers under 10 years of age were more than twice as likely to sustain lower extremity equipment related injuries than children above that age. Fractures of the lower extremity accounted for 21% of the injuries in the group of youngest children. In older children (in the 10 to 14 year age group) 18% suffered head injuries compared to only 5% of the very young children. Beginners had a nine-fold increase in risk as compared to more skilled children. Giddings found a six-fold increase in the incidence of fractures of the lower leg in children 12 years or younger as compared to adults. They also noted that the common adult injury of sprain of the ulnar collateral ligament of the thumb's metacarpal phalangeal joint was virtually nonexistent in their group of children. Both of these articles stress that proper functioning equipment to protect the lower leg and ankle region is absolutely as important in children as it is in adults.

In the final paper in this section of epidemiology, Allegra and his co-investigators observe the incidence of knee injuries sustained in alpine skiing in central Italy. They observed that knee injuries accounted for 29.3% of the total injuries recorded over a 10-year period. The vast majority of these knee injuries involved knee ligament sprains (27.5%).

Biomechanical and Physiological Aspects of Skiing

This section of the text includes nine papers dealing primarily with biomechanical and, in some cases, physiological aspects of skiing. In these studies further efforts are made to better understand the forces and moments that result in skiing injuries. It is only through further study of these complex subjects that we are going to identify the means of reducing the incidence of injuries to the lower leg and the now epidemic problem of knee ligament injuries.

In the first article in this section, Chiang and Mote attempted to identify whether an isometric quadriceps contraction alone can produce sufficient anterior displacement of the tibia relative to the femur to rupture the ACL. It has been suggested by several investigators in the past that failure of the anterior cruciate ligament through quadriceps contraction

could result in ACL injury. The authors concluded that quadriceps muscle contraction alone could not result in ACL disruption.

Schaff and Hauser evaluated the effect of varying the stiffness of the posterior aspect of the ski boot as a means of possibly reducing the risk of knee injury. They felt that the rigid fixed dorsiflexion of most ski boots is affecting the incidence of knee injury in skiing. They felt from their studies that it is possible that a ski boot that is less stiff posteriorly or which would respond by giving way when a certain amount of rearward force is applied by the falling skier could possibly reduce the risk of knee injury. It remains a challenge to these authors as well as others to prove whether this concept can actually assist in the reduction of knee ligament injuries.

The work by Berns and co-authors was an experimental study in an attempt to identify the loads and strains that disrupt the anterior cruciate ligament and the medial collateral ligament in a laboratory situation. They found as expected that the anterior cruciate was failed by anterior translation of the tibia relative to the femur and the medial collateral by a valgus type of loading. They reported a large variation in ligament strain at failure. Their attempts to develop an empirical model which could adequately predict strain measured in the load to failure test could not be done accurately. This inability to make accurate predictions was believed to be due to the subinjury load levels used to determine the empirical model. The study demonstrates the ongoing frustration to clearly identify the loads and strains causing failure of the ligaments that result from skiing injuries.

Yee and Mote provided their complex methods of establishing the forces and moments at the knee and boot top that occur in skiing as a result of changes in the stiffness of the ski boot. Their data was gathered from six subjects skiing a slalom course using boots of various stiffness. Their regression model provided data for the moments at the boot top and knee. They found that bending moments at the boot top and knee are not clearly related to ankle flexion and that maximum bending moments at the boot top do not necessarily occur at maximum ankle flexion.

Quinn and Mote provide the readers with an analysis of the forces and moments on each cross section of the leg between the ski boot top and the knee during recreational skiing that were predicted from measurements of the force and moment under the toe and at the heel of the boot and the flexion angle of the ankle. The torsional moments at the boot top and knee joint are better predicted by the medial-lateral force acting at the toe in comparison to the medial-lateral force at the heel. They found that the varus valgus moment at the boot top and knee are better predicted by the resultant medial lateral force component at the base of the boot, than by the medial-lateral force at the toe or by the medial lateral force at the heel. The set of forces that included the force normal to the ski at the toe, the force normal to the ski at the heel and the component of the total force normal to the ski directed perpendicular to the leg were better at predicting the anterior posterior bending moments at the boot top and knee, than the force normal to the ski at the heel or the force normal to the ski at the toe, or linear combination of those two forces.

Plitz and his associates investigated ankle fractures using a special testing device and human cadaver material. They concluded that torsion of the lower leg relative to the tarsus may occur in modern high and stiff ski boots even if they are properly fastened. They also noted that the Lauge-Hausen method of classification of ankle fractures needs to include simple inversion and eversion to be fully applicable to ski induced ankle fractures.

Nordsletten and Ekeland demonstrated in a rat model that tetonic muscle contraction dramatically increased the amount of bending moment that could be withstood by the rat's tibia compared to the state where the muscle was not activated. The increase in average ultimate bending moment at failure was 76%, and the ultimate energy absorbed with con-

traction occurring was 230% above that when the tibia was not supported by a contracting muscle. This study emphasizes the need to consider the effect of muscle contraction on the strength of tibias when considering the function of ski bindings.

Schaff and Hauser in a study of the use of 3-D video motion analysis to study differences in skiing techniques in regards to vertical acceleration, upper body rotation and angular displacement of the knee were found to be practical and offered the potential opportunity to not only enhance the performance of the skiing athlete, but also potentially to lead to the means of injury prevention.

In the final paper in this section Grappa et al. demonstrated the ability of a device that can be used in the laboratory to simulate the activity of skiing. They believe that their efforts demonstrated that their ergometry device had potential to provide an effective level of muscle training, the ability to identify stylistic errors in skiing technique and also to be an effective tool to evaluate rehabilitation following injury by means of testing muscle rehabilitation and propreceptive recovery.

Ski Bindings

The two papers presented in this section represent the work of the same research team from Davis, California. Caldwell et al. describe a new design concept for the mechanical release of the heel of a ski binding activated exclusively by the anterior posterior bending moment at the boot sole rather than an upward force at the boot heel. This design change over the standard heel release mechanisms was produced in a prototype model that worked successfully. The authors challenged themselves to develop a skiable prototype of this device.

In the article by Eseltine and Hull, the authors continued their work on the development of electrically modulated twist release of an alpine ski binding. The goal of this release mechanism is to monitor the activity of the quadriceps muscle group and alter the force at which the binding will release depending on the state of the muscle activity. Although this system could effectively alter the load required to release the binding, its excessive size and weight do not yet make it a practical device. The authors intend to work on these practical barriers so that in the future such a device may become available as a means of improving skiing safety.

Skiing Safety

Penniman in his work presents an approach that has rarely been used in past ski injury research endeavors by suggesting standards for marking and warning skiers of hazardous conditions that exist on the ski slopes. He makes suggestions for the principals of identifying these common hazards and the most common methods for mitigating them.

In the paper by Bergstrom et al., the authors discuss the means by which they have attempted to reduce the risk of injury to skiers at the ski area constructed for the olympic competition of 1994. The authors have developed an injury severity score for each injury and then marked the areas on the ski slopes where these accidents occurred. They felt that this model provided an excellent means of identifying where alterations upon the slopes may be used to reduce the risk of injury.

In the final article in this section, Ejnar Eriksson, the founding president of the International Society of Skiing Safety, provides the readers with the means by which the Swedish Ski Safety Council has been able to organize itself into an effective group working for skiing

safety and how they were able to enlist the support of the Swedish government in establishing their programs targeting skiing safety for the general population in Sweden.

Other Winter Sports Injuries

The first two articles in this section deal with the relatively new sport of snowboarding. Shealy in his work demonstrates that there are many similarities between injured downhill skiers and snowboarders. Downhill skiers had an injury rate of 2.66 per thousand skier visits compared to 2.99 per thousand for snowboarder visits. Forty-six percent of snowboard injuries involved the ankle and wrist, while those body parts constituted only 8.9% of the downhill injuries. The incidence of tibia fractures in snowboarding injuries is extremely low. This coupled with other findings suggest that a releasable binding is probably not a high priority item to improve the safety of snowboarders. It does appear that some type of conditional support system to the wrist and ankle may be appropriate in snowboarding populations.

Janes and Fincken's work was similar to that of Shealy in demonstrating that relatively few knee ligament injuries and thumb injuries are sustained in snowboarding than in downhill skiing. The high incidence of ankle and distal radius fractures suggest further efforts are needed to reduce the risk of injury to these body parts. Concern was expressed by both Shealy and Janes and Fincken concerning the trend toward stiffening of the boot for snowboarding. Neither author could state that there was any significant change in the distribution of lower extremity injuries, but certainly the implication of moving the problem from the lower leg up to the knee has to be the least of concern. Obviously a need for more longitudinal studies on the distribution and incidence of snowboarding injuries are indicated as the sport evolves.

Yamamura and his co-authors evaluated 43 ski injuries that occurred between 1985 and 1990. Their rate of injury was 5.4 per thousand jumps. They also reported 9.07 falls per thousand jumps.

In the final paper in this STP, Sherry and Biankin identify a sport apparently popular only in Australia in which individuals slide down a snowy slope on a small square plastic shell. This activity occurs on terrain that is adjacent to the ski slopes. The most common injuries involved the lower spine and pelvis.

Conclusions

The material presented in this book should allow almost any individual interested in skiing safety to find topics that are of special interest to themselves. The ongoing efforts in establishing the epidemiological aspects of skiing are presented in the first section of this text. The continuation of this type of work is certainly necessary. However, it must be stressed that careful attention must be given to following sound epidemiologic principles to assure that good study design allows the production of information which will be of help to future readers. In the past many epidemiologic studies have been flawed by improper design or attempting to draw conclusions from observational data without a knowledge of the population at risk.

The biomechanical and physiological studies presented in this work demonstrate the ongoing difficulty in establishing the big picture from complex research data. There are still too many factors not known about the mechanism and production of knee injuries. This makes it impossible for us to offer solid suggestions for methods to reduce the risk of injury.

The continuing interest in the ski boot and binding and how they relate to skiing safety are still subjects that need much more effort.

There is no doubt the overall injury rate is down a great deal from what it was 20 years ago, but it appears that the changes that are now occurring cannot assure a continuation of the improvement of these injury rates. Clearly the challenges are present to all individuals interested in skiing safety. We encourage all readers of the material in this book to use it as a basis for development of their own ideas and urge them to join with the rest of us who are working to reduce the element of risk as much as possible from the fantastic and pleasurable sport of skiing.

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