Overview

The International Society for Skiing Safety (ISSS) was founded in 1974 to bring together persons with a common interest in the reduction of the number and severity of snow skiing. The ISSS meets biennially for exchange of ideas and presentation of technical papers advancing our understanding of skiing, skiing injuries and their prevention. The lecturers and attendees at these meetings include: researchers from industry, universities, technical institutes; skiing professionals; entrepreneurs and the public. Following each meeting participants can submit their presented manuscripts for peer review and possible publication in the proceedings of the meeting. Since the 1983 ISSS meeting in Keystone, Colorado, the ASTM Committee on Snow Skiing (F-27) has joined the ISSS in the co-sponsorship of the symposia and the ASTM has also undertaken the publication of select papers in its Special Technical Publication (STP) series. This STP is the symposium volume from the tenth international symposium held in Kaprun-Zell am Zee, Austria during May 17–21 1993. The book contains thirty-seven papers out of the fifty-four submitted for consideration. Earlier volumes from the fifth through the ninth international symposia are found in ASTM STP volumes numbers 850, 938, 1022, 1104, 1182.

The purpose of this book is to provide the reader with current research, and professional and practical findings about skiing injuries. While the materials are works of the authors, the review and editing processes selected those manuscripts prepared following a high standard of research. The standard underpins the need to maintain the proceedings of the ISSS/ASTM symposia as the most substantial body of literature on skiing injury available. We hope that the papers in this book stimulate reader interest in reducing skiing injuries further and participating in the effort. We urge those readers not currently involved with the ASTM or the ISSS, and who share this common interest in the problems of skiing injury to contact the editors or the ASTM for information on involvement in this field. At the present time papers submitted for the symposium volume from the 11th international symposium held in Voss, Norway during April 23–29 1995 are in review, and plans for the 12th International Symposium to be held at Whistler, Vancouver during Spring 1997 are underway. For further information contact the editors or the ASTM.

Because of the interdisciplinary character of skiing research, the papers are grouped under six topic headings to add coherence for the reader. The first section, titled *Skiing Safety Organizations*, contains two tutorial papers discussing efforts by the National Ski Patrol and the ASTM Committee on Snow Skiing on reduction of skiing injuries. The second section, *Epidemiology of Skiing Injuries*, includes eleven papers that identify trends in injury rates and injury severity throughout the skiing world. The next section, *Biomechanics of Skiing*, contains nine papers addressing the mechanics of skiing and skiing injury. The fourth section, *Injuries to the Knee*, brings together seven papers addressing the most important, serious injury across the skiing population. A section titled *Other Winter Sports Injuries* follows with three papers. The final section, *Skiing Equipment*, contains four papers that address the concept, design, evaluation and value of ski release bindings and one paper on the mitigation of impact injuries.

Summary of Sections

Skiing Safety Organizations

Organizations dedicated to safety in skiing merit special commendation for their work in fostering and transferring knowledge to the public. In the first paper Bowman traces the historical development of the National Ski Patrol emergency care training programs from the beginning to the present. This tutorial paper documents this important chapter in volunteer emergency care practice. In the following paper Bahniuk provides a biographical review of the history of the US skiing standards established by the ASTM. It is written in a style that preserves the historical sequence and also captures a sense of the drama of the period.

Epidemiology of Skiing Injuries

Through the use of statistical methods, epidemiology of skiing injuries classifies injuries according to their rate and type for populations of skiers classified by age, gender, occupation, skiing equipment and experience, nationality and such. Identification of the more serious injuries and their possible causality are primary goals. The eleven papers in this section address injuries to skiing area employees, gender differences in injury rates, deaths in downhill skiing, injuries caused by collisions, facial injuries, injuries to snowboard skiers, injuries in large skiing areas in Sweden and Italy, and the marketing of skiing safety.

No significant difference in the injury rates to ski patrollers and instructors exist when they are compared to recreational skiers according to Belanger, et al. The area employees were less likely to experience serious knee injury, however. The authors provide a methodology for evaluating employee injury data at skiing areas of all sizes.

While the overall rates of injury in males and females of equivalent ability are not significantly different, three papers conclude that gender is a significant factor in the rate of particular injuries and their severity (Greenwald et al., Shealy and Ettlinger, and Cadman and Macnab). Women are at least twice as likely to suffer serious knee injuries than are men, and men have about three times the propensity for impact injuries, lacerations and dislocations than do women. An increasing incidence of tibial plateau fractures among women over thirty-five years of age is a new trend possibly associated with an aging skiing population. Young children and teenagers continue to be at the greatest risk of injury.

Death from downhill skiing typically occurs to a male skier who has suffered a head and/or neck injury from collision with a tree or other fixed object (Shealy and Thompson). The rate of one death per 1,800,000 skier visits has not changed over the past decade and makes skiing about seven times less likely to result in death than travel by automobile or commercial aircraft. In short, you can ski to work.

During collisions the victims of the collisions were much more likely to be injured than the causers, commonly young males, according to Burtscher and Philadelphy. They estimate that one of 4500 skiers in Austria was involved in a collision during the 1989 season, with the most common injury being trauma to the head. Gassner et al. also found an increasing frequency of upper body injuries in a two year study. More than 10% of all patients seen at their Innsbruck clinic were skiers and half of them were injured in collisions.

Lamont presents injury data collected by the New Zealand Mountain Safety Council on snowboard skiers for the 1991 and 1992 seasons. The paper discusses standardization of methods that permit comparison of data in this relatively new field.

Data on injuries in an Italian (Molinari et al.) and a Swedish (Made and Tarnaby) ski resort that were recorded over multiple seasons are reported. A greater effort to inform the public about safety and to provide for emergency care is called for. A one-year follow-up study showed that about one-third of the injured Swedish skiers continued with symptoms of their injuries. Alcohol was not found to be a significant causal factor in injury in the Swedish study.

Kisser et al. points to a sobering statistic that one of every 80 Austrian skiers is injured each season. He discusses a method of risk evaluation for Austria and designs an organization to increase safety while skiing.

Biomechanics in Snow Skiing

The applications of principles of mechanics to the skiing process is fundamental to the understanding and control of injury. The failure of tissues, which is injury, is a process where the generation of stress at an injury site exceeds the capacity of the tissue to sustain it without disruption. The process of stress generation in tissues and its control is the most important biomechanics problem we face. However, the mechanics of the skiing process itself, which is undertaken by the system composed of the skier plus skiing equipment tracing out trajectories in a skiing maneuver, is also important to understand if control of injury is the ultimate goal. The nine papers in this section address the importance of muscle contraction to fracture strength, prediction of injury producing forces at sites of common injury, use of ultrasonic techniques to track bone motions, use of video techniques to track three dimensional motions of skiers, analyses of aerodynamic drag and of friction between the ski and snow, predictions of skier trajectories over the snow after loss of control, forces transmitted from the snowboard to the skier, and loading to the leg during the backward fall.

Ekeland and Nordsletten show that (induced) muscle contraction increases substantially the ultimate bending strength of the tibia and the dissipated energy during bending of the tibia in young and adult rats. Their experiment simulated bending of the tibia at the boot top during skiing. The adult rats experienced substantial advantage in ultimate bending strength and especially energy dissipation when compared to the young subjects. The authors speculate that this substantial strengthening from contraction in the adults may explain the relatively lower incidence of fractures seen among adult skiers when compared to children.

Models that predict bending at the boot-top, twisting at the knee, valgus moment at the knee, and the anterior force at the knee from lateral and vertical force components at the bindings are presented by Yee and Mote. They show that the principal injury producing forces can be controlled only through control of the lateral and vertical forces at the toe and heel, which current bindings do not do. This deficiency in the state-of-the-art binding is demonstrated and is consistent with the common observation that current binding mechanisms can not control injuries to the knee.

A method for the tracking of bone motion beneath the skin using ultrasonic and imaging techniques is presented by Friedrich and Mote. The technique avoids bone tracking errors caused by motion of soft tissues when surface instruments or markers are used. On another scale of optical tracking Mossner et al. obtained a three-dimensional reconstruction of large skier motions during skiing for the purpose of inverse dynamic prediction of the forces between the skier and the snow. Prediction of forces at the knee is also an objective of this work.

Kaps et al. determined the coefficient of friction and the drag during straight running and traversing. The motion was measured and least squares techniques were used to fit models of a skier (particle) experiencing friction and drag forces of particular form but unknown scale. In a related work Nachbauer et al. investigated the friction of a test course under different snow and air conditions. One hundred and seventy five tests showed that friction could not be explained by single variables. Surprisingly, the authors found that snow temperature is not significantly related to friction between the ski and the snow. In another paper addressing friction Brown et al. used ballistic calculations to predict the trajectory of a skier over the snow following loss of control. The design of trails, instructions to skiers and placement of protective devices are aided by consideration, if not prediction, of expected skier trajectories.

The retention function of a release binding for snowboards is the focus of the paper by Bally and Taverney. The complete force and moment between the boot and the board were measured and they noted the maximum values correlated poorly with parameters commonly used to specify downhill ski binding settings like the height and weight of the snowboarder and snow boarding technique. This, of course, makes establishment of a setting criterion following concepts used for skiing problematic.

The effect of the ski-boot-binding system on the loading of the lower leg during the backward fall was studied by Senner et al. through experiments with an anthropometric dummy. The system provides the important opportunity to reproduce tests and test results. They observe that dynamic system tests simulating falling may be necessary for a satisfactory evaluation of equipment specifications.

Skiing Injuries to the Knee

Injury to the knee, especially complete rupture of the anterior cruciate ligament (ACL), has been the most common of the severe skiing injuries for the last decade and a half. While this injury was relatively uncommon earlier, and even the possibility of an isolated tear of the ACL was debated as recently as the late 1970's, it remains an uncontrolled epidemic in the skiing population. Attention to its modulation has dominated the rhetoric, if not the action, of the research community throughout this period. Seven papers in this book address treatment of ACL injuries in world cup level skiers, patellofemoral pain in alpine skiing, experimental systems for studying ligamentous injuries, protection of the ACL by muscle contraction, case studies of ACL injuries, computer simulations of ACL forces during backward falls, and assessment of occult fracture associated with ACL tears by MR methods.

Ekeland and Vikne studied five World Cup competitors who returned to competition following surgery and nearly regained their competitive positions within one or two seasons. Female World Cup competitors, who experienced patellofemoral pain after altering their skiing technique were studied by Aune et al. Evaluation of their techniques via video and CT scans of their joints did not reveal abnormalities in alignment. Their new skiing technique generated larger forces at the knee, however, a likely causal suspect to explain the concomitant pain.

A device for the general, in vitro testing of the knee joint ligaments is discussed by Bach and Hull. Control of general loading applied to the joint or motions across the joint are possible.

Barone et al. propose that a ski boot with a rear spoiler that releases under sufficient load may reduce the likelihood of ACL injury. They also observed that EMG signals from four muscle groups depend on the spoiler stiffness. High spoiler stiffness leads to imbalanced contraction between quadriceps and hamstrings probably resulting from standing in an unnatural position. A spoiler of lower stiffness leads to more balanced measures of EMG. They speculate that the design of the boot that results in balanced contraction might as a consequence better protect the knee from injury through the contractile forces crossing the knee.

Computer simulations of response of an open kinematic chain that represents a skier-ski system by Webster and Brown were used to predict the loading at the ACL during backwards falls. Increased speeds of skiing and stiffnesses of model elements increases the shear forces predicted across the knee.

Six case studies of skiers with ACL ruptures are reported in Fischer et al. where all occurred in twist with anterior drawer. They call attention to this injury mechanism and note that friction between the boot and ski-binding continues to be a problem.

Yamagishi et al. examined magnetic resonance images of thirty-six knee with acute ACL tears and observed twenty-two also suffered occult fractures. Initial radio graphs showed no evidence of fracture. They conclude that these fractures demonstrate that substantial compression occurs between tibia and femur during the typical ACL injury. The most common is an isolated occult fracture of the posterior aspect of the lateral tibial condyle. The next is a pivot shift resulting in a combined posterior lateral tibial and femoral condylar occult fracture. These large compressions across the joint have not been previously reported; their interplay in the mechanism of ACL injury may be quite important to consider.

Other Winter Sports Injuries

Tibial plateau fractures are .3% of all injuries recorded by Johnson et al. over a nineteen year period 1972–1991. The injured population were most likely older women who experienced binding release prior to injury opening the possibility that a blow to the tibia may have participated in the injury. The typical mechanism appears to be hyperextension with valgus.

Altitude sickness affects one of four persons going to elevations between 2000 and 4000 meters (Bobard and Schoene). This well-written tutorial paper alerts the reader to acute altitude sickness and the efforts needed to educate skiers about it.

The hypothesis that the greatest fatigue occurs on the third day skiing was tested and confirmed by Hofmann and Stockinger using the Ruffier Index and heart rate in experiments on a group of young skilled skiers. Fatigue is caused by glycogen depletion and restricted glycogen repletion.

Skiing Equipment

Skiing equipment serves to improve the efficacy of skiing and to promote reductions in the likelihood of injury. Equipment designs, which are commonly driven by skiing technique and the desire for improved measures of performance, are closely linked to observed patterns of safety and injury. Most changes in the patterns of injury observed over the past three decades have resulted from changes in the equipment design to improve skiing performance, not safety. In this section four papers address ski release binding problems including the use of fuzzy logic control in bioadaptive binding mechanisms, electro-mechanical bindings controlling torsion and bending of the leg, binding release in backward falls, and bindings appropriate for water skis. A paper on mitigating injury from impact with fixed objects concludes this section and the book.

The safety function of ski release binding designs should maintain the forces generated at the sites of common injury below an acceptable level. This level depends on the skiers weight bearing and muscle contraction, at least. The distinction between what is large and what is small weight bearing is imprecise or fuzzy, as is the distinction between large and small contraction. Fuzzy logic is a technique for quantifying imprecise, but significant, data for control purposes. Through the use of actual skiing data involving some falls, with and without binding releases, Crawford and Mote can test the performance of fuzzy logic binding designs against the performance of state-of-the-art products. They show that both inadvertent release and inadequate release of conventional designs can be corrected with the fuzzy logic design.

Neptune and Hull present an electro-mechanical ski release binding design with sensitivity to both twist and forward bending. The design focuses on control of moments developed at the injury sites, and the dependence of the strength of the knee joint on muscle forces that cross the knee. Bally proposes that backward release is one of the remaining improvements possible in existing mechanical bindings. His work investigated the upward release at the toe that would not result in inadvertent release while skiing and tried to correlate that value to skier weight for setting purposes. For aggressive skiers the correlation was poor, and for less aggressive skiers the correlation was improved. This negative result means research will have to broaden its view to find the variables for control of backward release.

A method for measuring the complete release forces for a water ski binding was developed by Merala and Piziali. The ski is clamped to a load cell and the skier executes self-release. The torsional release torque depends on the pressure of the foot against the ski—some heel lift is required to release the binding. Release torques required from water ski bindings are smaller than those recommended by snow ski release binding standards.

.The most popular methods of mitigating the severity of injury during impact with fixed objects are discussed by Penniman. Removal of fixed objects when possible, attention to collision during trail design to reduce the likelihood of impacts, and providing effective padding when necessary are means proposed to reduce impact injury rates.

Closure

The papers in this book present the opinions and findings of the authors. They have endeavored to employ sound methods, but nonetheless it must be understood that ideas at the forefront of a developing subject evolve. Accordingly, concepts, methods and in some cases conclusions are expected to change as our understanding becomes more complete.

After twenty-five years, study of skiing injuries has become a mature subject. The great gains in reduced injury rates were achieved more than a decade ago. They came about through solution of many important problems that did not require a deep understanding of the injury mechanisms. The difficult problems that remain require an understanding of injury to address and accordingly commitment and expertise by the investigators. The field is ripe with opportunity for the serious and prepared. Even after the substantial world-wide effort on these injuries, the primary problem—*control of the loading generated in specific tissues that are likely to be injured*—remains unresolved. The time has come to get serious about the hard problems.

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