Summary

The papers in this volume are separated into eight sections representing different emphases among the skiing injury problems. The first is concerned with standards and standards organizations devoted to skiing. The second is concentrated on the broad topic of biomechanics in skiing. The equipment research papers on ski boots and ski release bindings are featured in the third and fourth sections. The changing patterns of skiing injuries are discussed in the fifth section, on epidemiology. Treatment of injuries, injuries from cross-country skiing, and first aid and cold injuries are summarized in the sixth, seventh, and eighth section.

The first five papers are different from the remainder because they were specifically solicited by the symposium organizers to be presented by the authors. This was done to highlight the work by several standards organizations around the world. The remaining papers were offered by the authors in response to a Call for Papers sent out to individuals known to be interested in skiing safety.

Organizations Working to Improve Skiing Safety

Bahniuk and Hulse summarize the history of ASTM involvement in skiing safety and the procedures by which voluntary standards are developed through ASTM. An outline of ASTM Committee F-27 on Snow Skiing is presented. They point out that the time required to develop consensus standards produces fruitful results through meaningful documents and valuable education for those participating. The following two papers, by *Asang* and *Wittmann and Hauser*, were solicited by the symposium organizers to provide the reader with an understanding of the work of the Internationaler Arbeitskreis Sicherheit beim Skilauf (IAS) and the Technischer Überwachungs-Verein (TÜV) Bayern and their relationship to the German Institute for Standards (DIN).

Bally reviews the organization of skiing accident prevention in Switzerland. He points out that improvements in equipment have led to lower binding setting recommendations, and he remarks that the reduced injury rates are the result of equipment improvements, improved skiing technique, and fewer adult beginning skiers. *Ettlinger* reviews standards writing bodies in the United States and Europe and discusses the need for meaningful standards. A weak standard lends credence to poor products; a strong standard can have severe economic impact, possibly without justification. He feels that the continuing high rate of knee injuries is traceable to standards, which fail to include protection of the knee as a criterion.

Biomechanics Related to Skiing

Menke et al estimate the tibia cross-section diameter from application of the weight and height of a person and also from application of the tibia head dimension as measured with calipers by the IAS method. They conclude that height and weight are better correlated to the tibia diameter than the caliper measurement at the tibia head. The sex of the person gave the best statistical prediction of the tibia head diameter.

Louie et al report on an investigation of the application of integrated electromyogram (EMG) signals to the prediction of externally applied torsion to the lower limb. In the laboratory a linear relationship between torsion and integrated EMG measurements was observed with correlation coefficients of 0.98. In skiing, however, the function of the musculature in posture and body position control dominated the contributions to supporting torsion. During falling and during binding releases the integrated EMG signal indicated significant muscle activity.

A laboratory system to investigate the function of the musculature during forward falls and during binding release was developed by *Bodem et al.* Forces and movie films were also simultaneously recorded. The preliminary results show release of the bindings occurring in 5 to 75 ms.

Kuo et al measured the bending and torsion transmitted to the lower limb while skiing and the forces acting on the binding. The paper shows that the lateral force at the toe can control torsion of the lower limb, but the bending of the limb cannot be controlled by the heel hold-down force in any toe/heel binding designs. The force under the ball of the foot is a better predictor of bending of the tibia than the heel hold-down force. During skiing, bending of the tibia by moments exceeding the adjusted release value for the binding by 100% and exceeding the expected ultimate strength of the tibia by 100% were reported.

Pain is the focus of *Medoff et al* in their study of the ski boot and the foot and leg. A plunger applied pressure to spots on the foot and leg, and the subjects subjectively responded with descriptive measurements of the pain level. The heel area was determined to be particularly sensitive to pain.

Lieu and Mote present the first research published on the optimal ski design for the "carved" skiing turn. The paper models the turning process and presents a criterion for comparing the carving efficiency of ski designs. Their model shows that the ski can carve only on the afterbody of the ski and that the carving ski must tilt up out of the snow at the tip by pressing the tail deep into the snow.

Figueras et al review injuries at the knee over the last two decades in three skiing areas in Spain. They discuss an injury of the knee of increasing incidence that occurs without the skier falling or the binding releasing.

Ski Boots

The paper by *Schattner, Hauser, and Asang* investigates application of a mechanical model on boot/foot interaction, including attention to muscle effects. They propose that the stiffness of the boot should increase linearly with the skier's weight, and the dissipation of energy by the boot design should increase with the skill of the skier. They conclude that pressure gradients should not exceed as yet unspecified limits. Because pressure gradients decrease with the boot shaft height, high boots are desirable for transmission of large forces. *Hauser et al* show that pressure distribution on the shaft of the tibia is strongly dependent upon the boot-shaft design. They also prescribe boot design requirements for the angle of the lower extremity to the vertical and the maximum pressure on the tibia. A method of measuring forces transmitted from the lower leg and foot to the ski boot during skiing maneuvers is reported by *Medoff et al. Lyle and Hubbard* investigate the optimal boot design for prevention of boot-top fractures, based on failure criteria for bending of the tibia. To prevent boot-top fractures the authors recommend that the forces between the boot and the tibia be applied as far up on the lower leg as possible. *Schattner et al* present a paper on a device for measuring the pressure distribution on the tibia during skiing. The system is an array of 24 by 8 capacitors with multiplexed signals displayed on a cathode ray tube at 25 Hz. The pressure is predicted by compressing an elastic, 3-mm-thick dielectric between the plates of the capacitor.

Bindings

Nagel and Reuleaux discuss the training and certification of sport shop personnel in Germany. They believe that the choice of equipment, correct mounting, and adjustment of the equipment will be of greater importance to reduction of injuries than improvements in equipment design in the coming several years. *Ekeland and Lund* compare the release torques recommended by the IAS and the Schweizerische Beratungsstelle für Unfallverhütung (BfU) for a group of 362 recreational skiers in Norway. They observe that the recommended release torques are higher for the BfU technique than the IAS in the majority of cases. They express concern that the relative difference is greatest for women, children, and beginners, for whom the risk of injury is known to be higher.

Ekeland and Lund also tested the release bindings of 376 alpine racers in seven competitions during 1982 and 1983. They found that only 10% of the racers adjusted their equipment within $\pm 10\%$ of recommended standard adjustments. The mean release torque was 50% greater than the recommended value. *Brown and Ettlinger* show that, in specific maneuvers, the release of all heel bindings could be produced even at release adjustments far above recommended levels. The authors propose that the retention problem observed is caused by the mechanism of sensing the forward lean release in existing binding designs. They propose that the heel hold-down force is not a good indicator of bending of the leg.

A review of electronic bindings is given by *Hull* in his paper. The paper presents the development of electronic bindings by the author and others. Designs are classified and critiqued. Only two disadvantages for electronic bindings exist, according to the author. The cost may be higher than that of a mechanical system, and the skiing industry is not prepared for this level of technology. The author concludes that electronic bindings eliminate many problems of mechanical designs and offer the potential for reducing both the frequency and the severity of skiing injuries.

MacGregor and Hull report on field tests with a microcomputer-controlled ski release binding. The authors suggest that longitudinal twist across the knee, predicted by their computer models, and pain thresholds in conjunction with muscle activity may be useful indicators for binding release.

Epidemiology of Alpine Skiing Injuries

A paper by *Shealy* reviews the ways in which statistics have been used and, in some cases, misused in previously published epidemiology studies of skiing injuries. *Ekeland and Holm* show that 1.4 injuries occurred per 1000 skier days among a group of Norwegian racers during the 1981/82 season. The injury rate in downhill racing was ten times that in slalom and giant slalom. Fifty-four percent were injured in the final third of the race, which suggests that fatigue was a contributing factor. Racers in the 16 to 29-year-old age group were more likely to be injured than younger skiers.

Shealy reports on an analysis of 8 million skier visits, with 17 000 injuries from 13 skiing areas across the United States between 1978 and 1981. The study reports that there were 2.18 injuries per 1000 skier days. Fractures of the tibia and ankle decreased, as well as lacerations caused by flailing skis, which have decreased with the introduction of the ski brake. *Lystad* reports a remarkably low injury rate of 0.91 per 1000 skier days in one Norwegian skiing area. He speculates that the superior skill of Norwegian skiers in the area may have contributed to the low rate. He concludes that children are most at risk and that no injury was reported from inadvertent release.

Danielsson et al review the development of skiing safety in Sweden and the methods undertaken to promote safety. They review the effectiveness of the campaign to educate and inform the public on skiing safety practices. A cost-benefit analysis showing the economic value of reduced injuries is discussed.

Hauser, Asang, and Müller conclude that beginners and children have a higher risk of all types of injury while skiing. The lower extremity equipment-related injuries could not be explained by the number of falls alone. They remark that an increased incidence of knee injuries may result from high boots, though that was cannot be concluded from their data. They note that the low knee injury rates among experts speaks against a causal relationship between high boots and knee injuries. The severity of injuries to experts has increased recently.

In his third paper, *Shealy* states that the annual death rate in skiing is 0.2 per 100 000 skiers, in comparison with football (2 per 100 000) and automobile accidents (26.6 per 100 000). Death is usually caused by head injury, followed by chest and torso injuries, often resulting from loss of control at a high rate of speed and collision with a tree. He cautions area operators about overly grooming their slopes, thereby permitting a higher rate of speed.

Jenkins, Johnson, and Pope report that collisions were responsible for 18% of all injuries at Sugarbush North Ski Area in Vermont from 1972 through 1982. Collision injuries were in general less severe than other injuries, except for collision with trees. Skiers involved in collision injuries were generally more skilled and more often male. However, females were more often involved when two skiers collided.

An evaluation of 168 injuries resulting from accidents involving T-bar ski lifts occurring at two Swedish ski areas is provided by *Lindsjö et al*. The most common injuries involved relatively nonserious lacerations of the head and face. Of all injuries treated, 7.5% resulted from T-bar accidents, but only 1 injury was observed for every 80 000 trips. Among several suggested means of reducing the danger was better supervision and padding of these lifts.

In a related study, in which *Lindsjö et al* also evaluate 258 head injuries treated at two Swedish ski areas during three seasons, these injuries accounted for approximately 11.4% of all injuries observed. Most of the head injuries were relatively minor in nature, but 43 concussions and 1 death resulting from a basilar skull fracture were reported.

Young and Crane present the results of a 16-year study of ski injury epidemiology at Waterville Valley, New Hampshire. Up until 1971 they had observed a steady drop in the injury rate, but thereafter it had remained quite stable at 3.5 per 1000 skier days. Their greatest concern involves an increase in the incidence of thumb injuries, which appear most likely to occur to advanced skiers falling forward in high-speed accidents.

Treatment of Injuries

Binet et al discuss the treatment of shoulder dislocations reported by a medical society whose members practice in French ski resorts. The type of accident, reduction methods, therapy, and recurrence were discussed.

Cross-Country Skiing Injuries

Boyle et al present a controlled prospective study of injuries at ski touring centers over two consecutive seasons in Vermont. The injury rate was 0.72 per 1000 skier days, with most injuries occurring to relatively inexperienced individuals skiing on downhill terrain. They suggest that heel plate design may be a contributing factor in the production of lower extremity injuries. *Shealy* compares the types of injuries produced by cross-country and downhill skiing accidents. He concludes that the distribution of injuries produced is remarkably similar. He also suggests that trends in cross-country equipment now becoming available may lead to greater frequency of lower extremity injuries classically associated with downhill accidents in which the bindings failed to release. The final paper in this section presents the views of *Ekstrom* on the basic biomechanics of cross-country techniques. From these analyses, he provides suggestions for an adjustable camber control device, a releasable cross-country binding, and a system to evaluate the optimal gliding characteristics and pressure distribution of the ski on the snow.

First Aid and Cold Injuries

Infrared thermography in the evaluation of clothing, ski boot insulation, and rescue are discussed and demonstrated by *Roberts*. *Bowman* stresses the need for skiers to have a working knowledge of heat production and conservation. He observes that a mildly hypothermic subject (rectal temperatures above 32°C) can be rewarmed in the field, but a moderately hypothermic subject (rectal temperature below 32°C) must be evacuated for complex medical care. Ventricular fibrillation is a common complication of cold injury and should be prevented by gentle handling. Hypothermia in the Australian snow fields and the methods used by the ski patrol to treat hypothermia patients are discussed by *Crombie*. The concept is one of active rewarming commenced as soon as possible and continued even when the patient appears to be dead.

Ennemoser et al present the relative effectiveness of four types of chemical heat packs available in Austria. Their ability to generate heat and the length of time of heat production are quite variable. This must be understood by rescuers if successful treatment of cold injured patients is to be expected.

Conclusions

The papers in this book summarizing the state of research in skiing injuries reflect the character of a maturing subject built upon a body of literature and generally accepted findings. There are no closed topics in the skiing injury field. Skiing equipment, slopes, and techniques change with sufficient rapidity that those attacking the high rates of injury are continuously chasing an elusive foe. Clear importance is assigned to the high rates of injury of the knee, the ineffectiveness of all practices to date at reducing the knee injury rate, and the probably increasing seriousness of those injuries.

The importance of the musculature in the injury problem is beginning to be recognized in research. The attention to this area will probably be fruitful in the future. The forces on the lower limb while skiing are reported to be substantially in the range of potential injury in more than one of these papers. This raises interesting questions about both research and present standards. If the forces experienced by the lower limb are in fact considerably greater than was previously thought, what does that mean for standards recommendations that are based on a physiological strength measurement that does not include the musculature? Will the basis for our standards have to be redefined?

Continuous attention to research on the contribution of the boot to the injury problem can be expected to provide fruitful information in the future. Further tuning of the stiffness of the boot to the lower limb to avoid excessive bending of the lower limb and excessive pressure on the foot is expected.

The national standards organizations are well developed and are functioning efficiently. More attention is expected toward unified international standards incorporating the essential features of the current national concepts.

Robert J. Johnson

University of Vermont College of Medicine, Burlington, VT 05405; symposium chairman and editor.

C. Daniel Mote, Jr.

University of California, Berkeley, CA 94720; symposium chairman and editor.

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