Summary

The papers in this volume are separated into ten sections representing different emphases among the current skiing injury problems under study. The first two sections concern "the knee." Injuries to the knee are considered by many to be the most important area for current attention in skiing injury research. The third section brings together papers on the biomechanics of both cross-country and alpine skiing. The next three sections contain papers with their foci on equipment issues: ski boots, testing and adjustment of ski bindings, and electronic designs for ski bindings. The epidemiology of skiing injuries in Japan over a long period is presented in the seventh section. Spinal injuries, other winter sports injuries, and first aid and treatment are covered in the eighth and ninth sections. An organizational effort to reduce skiing injuries especially among competitors is described in the tenth section.

The papers presented are contributed by authors who responded to a Call-for-Papers sent out to individuals and organizations known to be interested in skiing safety. Only a small fraction of the papers contributed to the Naeba Symposium, are published in this volume following the rigorous peer and editorial review required by ASTM publication.

Biomechanics of the Knee

Mathematical models of longitudinal and varus-valgus rotations across the knee are identified in laboratory and snow skiing tests by Kuo and Mote. The models predict rotations of the tibia relative to the femur caused by the forces of skiing. Comparison of theory and experiment shows some promise for application of models identified in the laboratory to predictions of rotations caused by the forces in skiing.

The contribution of particular muscle groups crossing the knee to the stiffness of the knee joint in torsion is investigated by Louie and Mote through experiments in which the subjects are trained to maintain self-induced contraction. Stiffness increases of 400%, because of contraction of the musculature at the knee, are reported.

Injuries to the Knee

Figueras et al. observe that anterior cruciate ligament and meniscule ruptures are associated with falling backwards or with skier's efforts to avoid falling...
backwards. That is injury occurred without the falling of the skier in about half their cases. Simultaneous contraction of the hamstrings and the quadriceps, translating the tibia forward relative to the femur, is proposed as the mechanism. Ekeland and Thoresen discuss the isolated rupture of the anterior cruciate ligament in a female competition skier who they were video-taping at the time of injury. The circumstances of injury reported are similar to those independently reported by Figueras et al.; a clear description of the injury mechanism is obtained from these papers. Shino et al. report that the isolated tear of the anterior cruciate ligament is more common than its combination with tears of the medial ligaments at the knee. They also associate the mechanism of injury to vigorous contraction of the quadriceps. They further discuss surgical treatment and case studies of patients.

Biomechanics in Cross-Country and Alpine Skiing

Study of the biomechanics of falling are under continuous development by Menke and Bodem. In their paper here they utilize electromyographic (EMG), kinematic, and dynamographic methods to uncover the mechanism of force generation in the musculature during falling. They found that 100 ms are required to develop EMG activity following the beginning of a frontal fall (that is, an additional delay of from 15 to 80 ms occurs before development of significant force from contraction). The mechanism of the frontal fall is essentially different, depending upon the activity of the musculature.

A historical perspective of the properties of the alpine ski over the past eleven years is the subject of the paper by Sakata. He postulates two conclusions following testings of 763 pairs of skis: (1) torsional rigidity is not of critical importance to skiing and (2) flexural rigidity is a very critical parameter for the performance of the ski.

Cross-country ski bindings with release function are called for in the paper by Ekström. This has become more important in recent times because the increased structural strength of cross-country skiing equipment increases the forces that can be applied to the limbs and torso before structural failure of the skis, bindings, or boots themselves. The pattern of increased strength in cross-country equipment follows that experienced with alpine skiing equipment over the past 30 years.

Ski Boots

Shealy and Ettlinger present findings supporting the conclusion that forward flexion in ski boots should be sufficiently high that the forces generated by the shin bone pressing against the tongue of the boot are effectively transmitted to the heel binding mechanism. They suggest that insufficient stiffness of the boot may, in some cases, be a major factor in bending fractures of the tibia.
Walkhoff and Bauman discuss basic physical parameters in ski boot design and discuss the evolution of design from qualitative to quantitative evaluations. They discuss stiffness and hysteresis energy losses found in boot tests at low temperatures with prostheses and with human subjects. They conclude that prostheses can not, as yet, reliably reproduce the boot hysteresis properties found with human subjects. This important result is consistent with observations of others, and it identifies an important question for the effective, quantitative, evaluation of ski boot properties.

Schaff et al. utilize measurements of the pressure distribution along the shaft of the tibia to analyze the safety and functional properties of ski boots, and to classify boots. The pressure measuring instrument is published in ASTM STP 860. The pressure measurements present excellent opportunities for further study of the mechanics of injury as well.

Yamagishi and Yahashi discuss a problem termed the ski boot compression syndrome in their paper where anterior compression at the ankle causes neuritis of the deep peroneal nerve and tenosynovitis of the extensor tendon. The problem, its causes and treatment, is described.

Ski Bindings: Testing and Adjustment

Ekeland and Lund conducted on-slope evaluations of the bindings of alpine competitors. They found that the ski bindings that functioned properly were, statistically speaking, less than one-year old, properly mounted and adjusted, and the release mechanism had been operated with the previous week. They recommend that the bindings should be self-released each day before skiing. Comparison of the recommended settings of the International Association for Safety in Skiing (IAS) and the Swiss Association Accident Prevention (BfU) standards for the competitors above is the topic of the second paper of Ekeland and Lund. The recommendations of the BfU are higher than the IAS for adolescent girls (24%) and boys (15%), and lower than the IAS for adult males (10%). They note the difficulty in measurement of the tibia head diameter in the IAS method may have contributed to the difference.

Attention is directed to the importance of the boot material and the interface of the boot and binding to the function of the bindings designed for children in the paper by Gundersen. In addition to a call for a technological standard for the boot and binding designs that is at least as stringent as that for adults, the author calls for increased guidance of children who are just beginning to ski.

Deviation in the expected binding release setting from the "ideal" value because of the unavoidable and permissible ranges the parameters used in the setting of the binding is the focus of the paper by Delouche. He shows that a binding that is properly adjusted, designed, and manufactured (that is, all adjustments are within their recommended ranges and the binding mechanism operates within its allowable tolerances) can deviate 20 to 25% from a desired setting no matter what standard is used. He suggests that the "ability correction"
is the critical factor leading to the deviation in setting. He further feels attention should be directed to evaluation of the boot-binding system with less emphasis on details on the component properties, which causes this circumstance.

The importance of the binding test machine in the operation of sport shops is the theme developed in the paper by Nagel and Mösch. They discuss the history, types of test devices, and the possibilities for the future. They believe system testing is the only method for control of the unavoidable variables in the system, a conclusion not different in principle from that of Delouche. It is necessary for all sport shops to system test their equipment, they state.

A recent binding concept, the Nava Binding, is compared with a Geze binding through laboratory release tests using an instrumented dummy by Bahniuk and Strunc. They report no surprising results with the Nava design and general satisfaction with its function.

**Ski Bindings: Electronic Design**

The two papers in this section by Hull et al. continue a line of electronic design and invention of bindings that has been underway for some years. Halsted and Hull enthusiastically discuss the design, field test, and successes of one microcomputer binding unit in their paper. The companion paper by Hull and Wunderly presents a new force measuring system (dynamometer) to be used with electronic bindings. The dynamometer has small cross sensitivity in the measurements, a significant problem in force measurements between boot and ski.

**Epidemiology of Alpine Skiing Injuries**

The papers in this section present data on injury rates that were here-to-fore not available outside of Japan. The data span many years of observation, Kuriyama and Fujimaki summarize injury data recorded over the past 28 years at their clinic. They point out that about 20% of the population of Japan skis (about 20 million skiers) and that the injury rate is increasing with knee sprains, fracture to the lower leg, and lacerations to the head and face all increasing in frequency. Ankle fractures and sprains are reported to be decreasing. Injuries patterns at Sapporo between 1979 and 1984 are discussed by Sugawara, Serita, Takada, Watanabe, and Kondo. About 40% of their injuries occur in children. Their observations show that fractures and sprains are commonly observed in children, sprains in adolescents, lacerations in male adults, and sprains in female adults. Fractures in children tend to be of the spiral type, while those in adults tend to be of the oblique type, similar to observations by others. They call for increased attention to the reduction of injury rates in the child population group, echoing the opinions of others; see the papers of Gundersen in this volume.

Air temperature is a new variable governing the skiing injury rate process, according to the paper of Serita. This conclusion was derived by study of 25
years of injury data at Sapporo. He proposes the thesis that the ski patrol can utilize the air temperature to indicate an increased likelihood of injury, thereby permitting preemptive actions to be taken. Such might include the warning of skiers or closing higher risk areas.

Injury rates and circumstances in the 12 to 15 million skiers in West Germany are discussed by Zink and Glaeser. They report approximately 80,000 injuries per year or a relatively low injury rate or 1.6 per 100 skiers per day (that is, injury rates of 3 to 4 per 1000 skiers per day are often reported). Of the injuries about 500 are torso traumas, and 42% of those are injuries to the kidneys, predominantly in males. They reported that the cases of torso trauma cost an average of about 6000 DM (approximately $3300) each.

Other Winter Sports Injuries

Ten cases of dislocation of the thumb (carpometacarpal) occurred during 1981–82 and 1982–83, when skiers jammed their thumbs longitudinally into the snow while holding their ski poles, report O'Connell et al. No previous cases were reported among the 3171 injuries recorded over ten years. No clear mechanism is verified though the retention of the pole during a fall may contribute to the dislocation mechanism.

Matsuda discusses the occurrence of anorectal abscess following hip contusion during skiing. The four cases presented stimulate new thought on this little studied area of skiing injury.

Two cases of spinal injury are discussed by Hirakawa and Oda. They confirm the finding that the incidence of such injury is low, by reporting 3 spinal injuries in the 12,000 injuries treated at the Nozawa resort during the past 10 years.

First Aid

The current use of a helicopter evacuation system is discussed from first hand experience in the paper by Binet. He reports about 25% of the injured skiers are assisted by the helicopter service in one or another way, and further he proposes that any skiing area serving 10,000 or more skiers must have a service.

Organizations and Safety

Rass points out that about one third of the committees of the International Ski Federation (FIS) are concerned with the safety of the estimated 200 million skiers in the world. By his estimate there are 3 million annual skiing injuries. He summarizes the efforts of the FIS in the areas of both recreational and competitive skier safety.

Conclusions

The state of research in skiing injuries is summarized in the papers presented in this book. There are no closed topics, and clearly all of the open ones have
not been given equal treatment herein. Skiing equipment, slopes, types of injury, and techniques of skiing change sufficiently rapidly that those studying the high injury rates are continuously chasing a darting foe. The injury rate at the knee remains the dominant skiing injury problem all over the world. There appears to be little to be proud of in the control of this injury problem; it may be increasing in severity. Explanations of the injury mechanism(s) and methods to reduce the injury remain at some distance from our current state of knowledge.

The contribution of the musculature to the protection against injury and to the increased stiffness of joint motions is being recognized for its importance in control of injury. There continue to be papers presented that report forces on the lower extremity far in excess of the potential injury levels because of the protection provided by the musculature. A time will come when this information can be utilized directly in the design of equipment to reduce the likelihood of injury.

The boot continues to receive attention for its contribution to skiing injuries. Attention to shaft stiffness, hysteresis energy dissipation, and more quantitative evaluation of boot designs regarding both comfort and safety is a trend that will probably continue.

The national standards organizations are well developed and functioning. The tendency towards developing a unified international standard incorporating features of the national standards through the International Standards Organization (ISO) is a welcome sign.

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