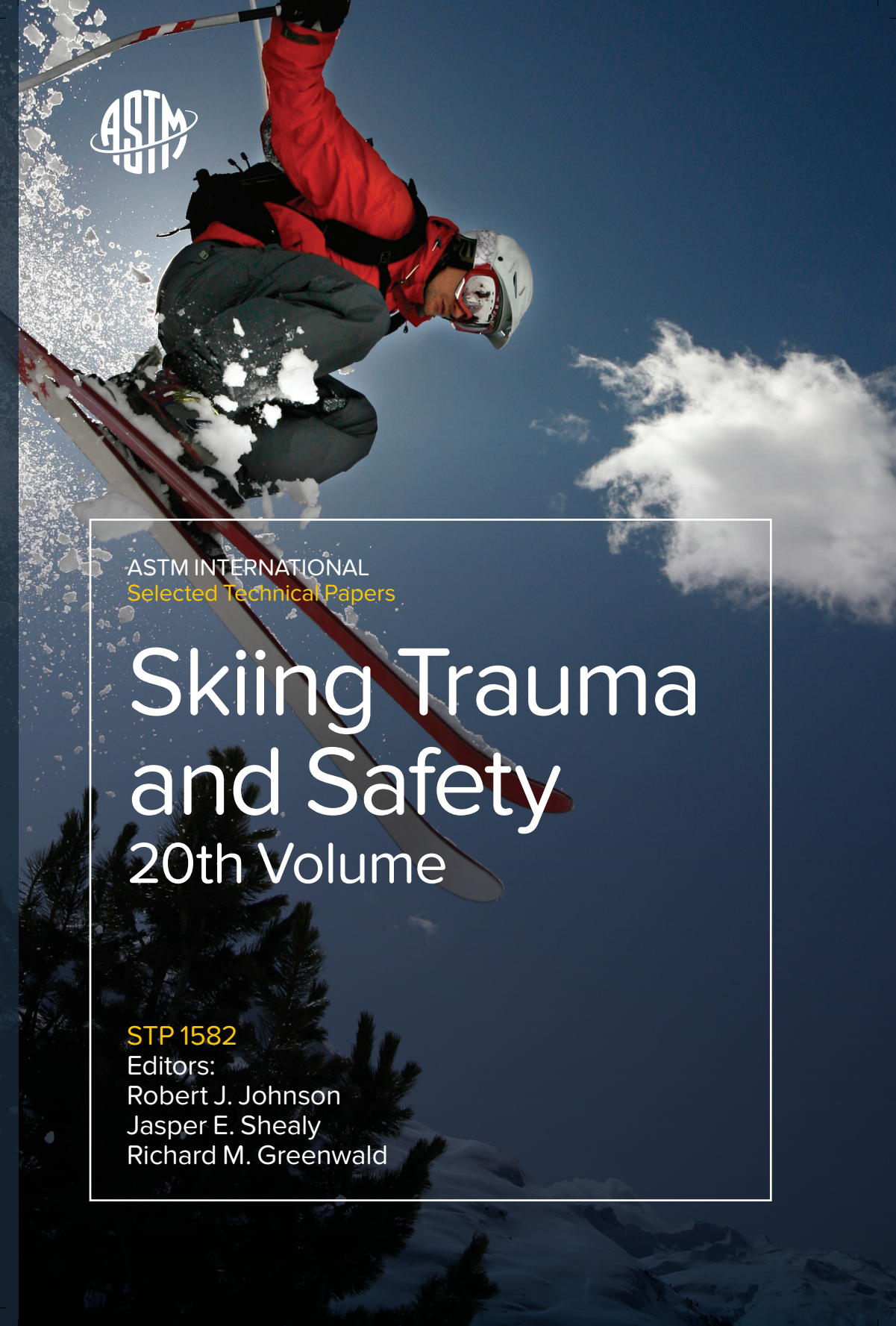

ASTM INTERNATIONAL
Selected Technical Papers

Skiing Trauma and Safety

20th Volume

STP 1582

Editors:
Robert J. Johnson
Jasper E. Shealy
Richard M. Greenwald

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Skiing Trauma and Safety: 20th Volume

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Foreword

This collection of the *Selected Technical Papers*, STP 1582, *Skiing Trauma and Safety, 20th Volume* contains 12 peer-reviewed papers that were among the 66 papers presented at the 20th International Society for Skiing Safety (ISSS) Congress in Bariloche, Argentina, on August 4–10, 2013. The meeting was sponsored by the ISSS and this publication is supported by ASTM International Committee F27 on Snow Skiing and Subcommittee F27.30 on Skis and Boots.

The congress chairman was Richard M. Greenwald, PhD, President, Simbex, Lebanon, New Hampshire, USA, and Adjunct Associate Professor, Thayer School of Engineering, Dartmouth College, Hanover, New Hampshire, USA. The STP editors were Robert J. Johnson, MD, Emeritus Professor of Orthopaedic Surgery, Department of Orthopaedics and Rehabilitation, University of Vermont College of Medicine, Burlington, Vermont, USA; Jasper E. Shealy, PhD, Consultant and Emeritus Professor of Human Factors Engineering, Rochester Institute of Technology, Rochester, New York, USA; and Richard M. Greenwald.

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Overview

The 12 papers published in this Special Technical Publication (STP) 1582 underwent a rigorous peer-review process before being accepted for publication. Since 1983, there has been a very cooperative relationship between the ISSS and ASTM International, working together to publish the proceedings of the ISSS Congresses.

The ISSS was founded by Ejnar Eriksson, MD, of Stockholm, Sweden. After the first World Congress on Skiing Trauma and Safety that occurred in Riksgränsen, Sweden, in 1974, the ISSS was organized. The first official ISSS congress was held three years later in 1977 in the Sierra Nevada of Spain. The chairman of that initial meeting was Jose Figueras. After the 1977 meeting, the ISSS has held its congress every other year at or near a ski resort in many parts of the world. The congress has been held at the following sites: Queenstown, New Zealand in 1979; Bormio, Italy in 1981; Keystone, Colorado, USA in 1983; Naeba, Japan in 1985; Chamonix, France in 1987; Riksgränsen, Sweden in 1989; Thredbo, Australia in 1991; Zell am Zee, Austria in 1993; Voss, Norway in 1995; Whistler/Blackcomb, British Columbia; Canada in 1997; Breuil Cervinia, Italy in 1999; Queenstown, New Zealand in 2001; St. Moritz/Pontresina, Switzerland in 2003; Arai, Niigata, Japan in 2005; Aviemore, Scotland in 2007; Garmisch-Partenkirchen, Germany, in 2009; Keystone, Colorado, USA in 2011; and San Carlos de Bariloche, Argentina in 2013. The next congress will be held in Cortina-San Vito di Cadore, Dolomites, Italy, from March 8-13, 2015. The chair for this meeting will be Nicola Petrone, PhD.

Since its inception, the objective of the ISSS has been to assemble individuals from many professions for the purpose of identifying, evaluating and discussing all aspects of safety concerning outdoor winter sports activities. Among those attending the congresses have been representatives of the skiing industry, equipment manufacturers, engineers from industry, universities and technical institutions, skiing professionals, including instructors and patrollers, competitors, physicians, lawyers, the general public, and representatives of organizations from all disciplines of outdoor winter sports. Many of the individuals active in the ISSS are members of ASTM International and other similar organizations from around the world.

Since the very beginning, the focus of the ISSS has been on the problems associated with alpine skiers, cross-country skiers, and ski jumpers. However, as time has passed new endeavors such as freestyle skiing, snowboarding, and skiboarding have been added to our areas of interest. The ISSS meetings are held over a five-day period that includes keynote addresses, podium papers, panel discussions, debates,

posters and demonstrations. In recent years there have been between 60–80 podium presentations at each of our meetings. A good deal of time has always been allowed for discussion so that varying views and interpretations of the many aspects of winter sports participant safety can be heard.

After each congress since the organizing meeting in 1974, the proceedings of the congress have been published in a book. Since 1983, there has been a very close relationship between ASTM International and the ISSS which has resulted in the publication of a Special Technical Publication (STP). To date, 16 STPs have been produced and provided free of charge to each active member of the ISSS. These include STPs 860, 938, 1022, 1104, 1182, 1266, 1289, 1345, 1440, 1464, 1474, 1510, 1525, 1553 and 1582. All previous STPs are still available for purchase by contacting ASTM.

Summary of Papers

The 12 papers published in this Special Technical Publication were divided into four categories: Helmets – 2 papers; Terrain Park Jumps – 3 papers; Epidemiology – 3 papers; and Skiing Equipment and Injury Prevention – 4 papers.

Helmets

In the first paper in this STP, Terwiel and Dickson devised an investigation to determine what snowsport instructors and the general public think the risks of snowsport head injury are and what they believe helmets will do for them within this risk environment. The reasons for helmet use or avoidance of use and whether greater knowledge existed among snowsport instructors as compared to the general public was also investigated. They found in their surveys of snowsports participants that the main reason for helmet use was linked with safety while the main reason for not using a helmet was linked to the lack of comfort, reduction in sensory awareness, and a lack of belief in the effectiveness of helmets. They found that respondents tended to vastly overrate the risk of injury and overrate the effectiveness of helmets to prevent injuries to the head area. They found little difference in the knowledge level of snowsports instructors compared to the general public. They hypothesize that the snowsport industry would benefit from an education program aimed at both industry professionals and the general public concerning the actual risk associated with snowsport participation and especially with regard to how affective helmets really are in protecting against traumatic brain injuries.

In the second paper associated with helmet use, Shealy et al. investigated the role of helmets in mitigation of head injuries using a case-controlled study of alpine skiers during the 17 seasons from 1995/96 to the 2011/12 season. During this interval, helmet usage increased from 8% to 84% in the population at risk. In earlier publications concerning the first several years of this study, it was demonstrated that injuries such as head contusions, scalp lacerations and even skull fractures were reduced by the use of helmets, but during that time it could not be proven that helmets were capable of significant reduction in other potentially serious head injuries. The results of the present study revealed that incidence of potentially significant head injuries declined from 1 in 4,200 days of activity to 1 in 11,000 days of activity. The present study revealed that the increased utilization of helmets that occurred in more recent years, once helmet utilization exceeded 50%, was associated with a significant reduction in potentially serious head injuries as well as all head injuries in general.

Terrain Park Jumps

In an effort to determine if the increase in jumping features in terrain parks from 1990-2010 has been associated with an increase in injuries, Shealy et al. analyzed National Ski Area Association data from resorts that had specific terrain parks. The number of resort visits, fatalities and catastrophic injuries were analyzed. The study found that the number of resorts that had one or more terrain parks with designed jumping features had gone from essentially none 1990 to 94% in 2010. During the 20 year analysis, the rate of fatal and catastrophic injuries and the overall incidence of any injury did not change. The perception that jumping features had resulted in an increased risk of injury was not substantiated by this study. The increase in the number of terrain parks with designed jump features has not been associated with an increase in catastrophic, fatal, or overall injury rates.

The second paper in this section, by McNeil et al., had two objectives: one was to demonstrate the feasibility or proof-of-principle of constructing a snow park jump that had a relatively constant Equivalent Fall Height (EFH) along the entire landing surface; and the second was to evaluate the impact performance between a standard tabletop jump and the constant EFH jump. It took experienced snow park operators about two hours to construct a small jump that complied with the profile requirements for a constant EFH jump. The impact performance of the constant EFH jump and the standard tabletop jump was measured using a jumper on a snowboard instrumented with accelerometers. Using the accelerometer channel on the snowboard perpendicular to the snow-plane surface, they were able to estimate the velocity changes at impact and from this they estimated the EFH of the landing. These were found to be in rough agreement with the theoretical expectations for EFH derived from the measured jump profiles.

In the final paper in this section, Scher et al. used an instrumented 50th percentile male Hybrid III anthropomorphic test device (ATD) fitted with snowboarding equipment to determine the head accelerations, cervical spine loads, and lumbar spine loads associated with landing on a snow surface while in inverted backward rotated configurations. The purpose of the research was to evaluate the injury mitigation potential of a landing surface that limits EFH. For these tests, the ATD was suspended above a hard-packed, snow-filled box, rotated backwards, and allowed to fall onto the snow. The ATD fall distance and backward rotation were varied in order to adjust the EFH (range: 0.23 to 1.52 m) and torso to snow angle at impact (range: 0 to 92 deg). For eight of the tests, the cervical spine compression exceeded the average compression known to create severe injuries. All of the tests produced cervical spine flexion moments above those associated with cervical spine failure found in the literature. There was no correlation between cervical spine compression and EFH ($R2 = 0.03$), but there was a correlation with torso to snow surface angle at landing ($R2 = 0.90$). The lack of relationship between EFH and the metrics related to severe neck injury in the testing suggest that landing configuration is more important than EFH in determining injury likelihood of cervical spine from an inverted backward rotated, unsuccessful jump landing.

Epidemiology

Shealy and colleagues used a retrospective stratified study design to evaluate injuries sustained at ski areas of different sizes in different areas of the country. This paper is the fourth in a series of studies to determine incidence trends at ten-year intervals. This analysis was based on ski patrol diagnoses of injuries at the various ski areas. This study generated 13,145 incident reports and an at-risk population of 4,618,000 visitation days. The incidence rate for skiing was 3.1 per 1,000 visits in 1980, 2.7 in 1990, 2.6 in 2000 and 2.5 for 2010. The snowboard injury rate was 3.3 per 1,000 visits in 1990, 7.0 in 2000, and 6.1 in 2010. The ski injury rate continued to decrease over the years while the snowboarding injury rate decreased only since the last study. The injury patterns for snowboarding versus skiing remains unchanged. The incidence of jumping related injury rates has declined since the last report. The prevalence of collision injuries with fixed objects has decreased. Terrain parks have not been associated with an increase in injury rates or prevalence of jumping injuries.

Uribe et al. presented a five-season study of snowsport injuries in western Japan near the city of Hiroshima. Each injured participant was asked to provide information about their demographics and skiing experience as well as the type of injury they sustained. The total number of injuries that occurred at Mizuho ski resort was 1,390 during the study period. Eighty-two percent of the injuries reported occurred while snowboarding, with 18% occurring while skiing. The incidence of injury to skiers and snowboarders was 43.5 and 56.7 per 100,000 skier/snowboarders. Among the skiers, 16.8% of injuries occurred to the knee joints, 12.8% to the shoulder, and 10.8% to the lower legs. Among snowboarders, 20.6% of injuries occurred to the shoulder, 12.5% to the trunk, and 12% involved the wrist joint. The authors observed that their study, unlike most previous investigations elsewhere in the world, revealed lower incidence of knee injuries among skiers and a lower incidence of wrist injuries among snowboarders. Also, the prevalence of snowboarders was dramatically higher in this investigation than previously published studies.

In the final paper in the Epidemiology section, Zacharopoulos and colleagues presented a case control study involving skiers and snowboarders at the Parnassus ski resort in Greece from 2007 to 2013 (6 winter seasons). They found that the injury rate expressed as mean days between injury was 283 days for skiers and 191 for snowboarders (the lower the number, the higher the injury rate). The incidence of snowsport injuries in Greece has declined from previous investigations published by the authors but remains higher than those reported from most other countries. Lower limb injuries were the most common among skiers (51.4%) and females have a significantly higher prevalence of lower limb injuries than males. Snowboarders suffered significantly more fractures than skiers (16.5% vs. 6.3%). The incidence of knee ligament injuries among female skiers is almost twice that of male skiers. Male snowboarders sustained more clavicle and shoulder injuries than female snowboarders, while women sustained more injuries to the wrist and have almost double the possibility of sustaining a wrist fracture than males.

Skiing Equipment and Injury Prevention

In the first paper in the section involving injury prevention, Dickson and co-investigators sought to determine the maximum speeds attained by pediatric snowsport participants in Australia. They had previously done similar work involving adult snowsport participants. Speeds were recorded on a continual basis using a GPS-based data logging device that enabled recording speeds, distance traveled and duration of participation. From over 700 hours of collected data, they found that the average maximum recorded speed was 44.1kph. They found that there was a significant difference in the average maximum speed across four levels of experience, but there was no significant difference between the average maximum speeds of females and males (42.5 kph vs. 42.4 kph). Likewise, they found no difference in the maximum speeds attained by alpine skiers and snowboarders (43.8 kph vs. 40.0 kph). This result is quite alarming when one considers that the average maximum speed of pediatric snowsport participants exceeds the testing protocols of all helmet standards in use.

In the final paper in this section, Costa-Scorse and associates explain to the readers that international standards call for the use of torque testing devices to assess the functionality of ski bindings with release values based on the parameters of age, weight, height, boot sole length and skier type. This cross-sectional study was done in New Zealand to determine the prevalence of use of the above-mentioned techniques. In a national survey of ski technicians and structured interviews with ski-industry personnel, the authors report that only 10% of ski technicians use the torque testing device and many did not take into account appropriate skier characteristics. The authors concluded that ski-boot-binding system inspection, routine torque testing, and consistent application of international standards for correct setup of ski-binding-boot systems continued to be elusive in New Zealand.

Skiing Equipment

Costa-Scorse and co-investigators analyzed the functionality of a ski rental shop fleet using ISO and ASTM standard practices for rental shop skiing equipment. A sample of 9% of the entire rental shop inventory was chosen for analysis using a Windersteiger calibration machine. Deviations from the standard were classified into three groups. Class I deviations did not require corrective action but indicated that increased sampling of the inventory was indicated. Class II deviations were those which require immediate corrective action. Class III deviations indicated that the equipment was worn or damaged in a fashion that requires removal from the rental fleet. The authors found a high percentage of Class I deviations (50%) in equipment used for two seasons, 95% in equipment used for three seasons, and 65% in equipment used for four seasons. Class II deviations that required immediate correction were found in 48% of the equipment with two seasons of use. Two percent of the rental fleet was found to have Class III deviations. The authors found that the heel pieces of the ski boot binding systems with two or more seasons of use were nine times more likely to be out of tolerance than those with only one season of use. There

was only a small increase in the proportion of toe pieces that were out of tolerance for older compared to newer ski boot binding systems. Their study indicated the policy of retiring rental equipment after 3-4 seasons of use appears inadequate to insure the rental equipment is safe.

Madura and Brown presented a paper with the intent of demonstrating the possibility of devising a binding system that would be capable of reducing the risk of an ACL injury of the knee without increasing the risk of inadvertent release of the equipment. The authors pointed out that the Grade III ACL injury is the most common serious injury in alpine skiing. It has been well established that most bindings are not designed to protect the ACL of alpine skiers. Since inadvertent release can occur and lead to significant injuries, any new system devised for prevention of ACL injuries should not increase the risk of inadvertent release. The authors examined ski binding function using axiomatic design with the intent of developing concepts for ACL protection without increasing susceptibility to inadvertent release. A functional-physical, hierarchical decomposition of the upper level ski binding solution was developed. Both release and absorption systems were examined for their ability to satisfy the functional requirements mentioned above. Concepts for injury prevention using energy absorbing devices were introduced. This work showed that upper level design solutions can be developed in ski binding systems that have potential to protect the ACL, allowing transmitting control loads between the skier and ski slope and avoidance of inadvertent release.

Concluding Remarks

The cooperation between the International Society of Skiing Safety (ISSS) and the American Society of Testing and Materials International (ASTM) has provided a forum for presenting, discussing and eventually publishing timely articles on the subject of snow sports safety. We intend to continue this association between the ISSS and ASTM and plan to provide publications which will contribute to safer participation for winter sports enthusiasts throughout the world. We extend an invitation to all those concerned about the problems of safety in winter sports to join us as we attempt to understand, document and eventually reduce the risk of injury based on the proceedings of our two organizations.

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