Skiing Injuries

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The practice of sliding across the snow with supportive implements may date back as far as 5000 years ago when early hunters and fisherman used crude animal tusks to transverse snow. Precursors of modern skis have been found in Scandinavia and Siberia and have been dated back to 2000 bc. However, the first written record of skis is attributed to Chinese historical accounts dating to 600 ad.242943 In the 6th century there is written record of an industrious group of Finns using rudimentary skis to increase their mobility on snow to gain military advantage over neighboring tribes. This same skill allowed them to defeat the Norwegians in the 12th century.15

Competitive skiing seems to have gotten its start in Norway in 1767, and within 100 years it was a well-established activity in the Scandinavian countries.24 In the mid-1800s skiing was introduced to the western mining camps of the United States. Although it gained some interest there, it was not until the Lake Placid Olympics in 1932 that its popularity in the United States began to soar.1529 In 1935 it was estimated that there were approximately 10,000 skiers in the U.S.; by 1946 this number had increased to 100,000. In 1976 it was estimated that there were four million U.S. skiers, with this number increasing to an estimated 14.5 million by 1987.102952 Since the middle to late 1980s the number of skiers has plateaued, with little increase in the total skiing population. (The boom in snowboarding, however, has continued to swell the ranks of those using the ski slopes as their site of recreation.) Today it is estimated that there are approximately 14.5 to 15 million skiers in the U.S. and 200 million skiers worldwide.

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THE EPIDEMIOLOGY OF SKIING INJURIES

The first comprehensive reviews of skiing injuries came from Sun Valley, Idaho.134759 Earle et al.13 reported an incidence rate of 7.6 injuries per 1000 skier-days between 1952 and 1957. When Tapper59 reexamined the Sun Valley experience in 1978, he found that the injury rate had declined to under 3 per 1000 skier-days. The early efforts of these researchers established a precedence for injury reporting in skiing, but their data are difficult to compare with more recent information. Clearly, the improved techniques of examination, particularly for the knee, have made it easier to accomplish a more accurate and complete diagnosis. In addition, ancillary tools such as MRI, CT scan, and nuclear medicine have allowed the modern physician to be much more sophisticated and complete in the diagnosis of injuries. These differences are abundantly clear when one looks at relative injury data in the review by Tapper.[59] A total of 71 cases of "internal derangement" of the knee are reported between 1969 and 1976. By contrast, Warme et al.[63] have found in their experience with injury data from 1982 to 1993 that ACL injuries alone constituted 16% of all injuries sustained.

Since 1972, Robert J. Johnson, MD, and his colleagues[30] in Vermont have tracked injuries at the Sugarbush ski area and have provided the most comprehensive data on injury incidence and injury trends in the United States. They found that the incidence rate for ski injuries declined by 44% between 1972 and 1994, with the majority of the decline occurring between 1972 and the mid-1980s, with little change since that time. The most recent data indicate 2.5 skier-injuries per 1000 skier-days. This is consistent with reports from other ski centers within this country and from around the world.[3101135-38555663] Although most reports show a steady decline in the injury rate, it is probable that the rates reported reflect an underestimate of the actual injuries sustained while skiing. Garrick and Requa,[20] in their review of injuries sustained by students in the Seattle area, found that only 40% had reported their injuries to the ski patrol and 58% to physicians, while 38% did not report their injuries to either. Based on this, it is possible and, in fact, probable that the actual injury rate from skiing approaches 4 to 5 injuries per 1000 skier-days.

Women and children appear to be at slightly greater risk of injury from skiing. For women, the incidence of knee injury appears to be higher than that for men, although the injuries women sustain are generally less severe, involving grade I or grade II sprains to the medial collateral ligament.[20] Skiing is not the only sport that has demonstrated a higher incidence of knee injuries in female participants. The incidence of ACL injuries among women has been noted to be higher than among men in several sports including basketball, soccer, volleyball, and team handball.[24394861] Skiing, however, is somewhat different from the other sports cited because the incidence of ACL injury is not higher in the female skier, but rather the incidence of less severe collateral ligament sprains (grade I and II) is higher in women. The explanation for the increased incidence of knee injuries in women in skiing and other sports is unclear. Extrinsic factors (conditioning, body movement, muscular strength, and skill level) and intrinsic factors (joint laxity, physiologic variables, limb alignment, notch dimensions, and ligament size) have been identified.[2274161] Huston and Wojtys[27] demonstrated differences in muscle strength, muscle recruitment order, and time to peak torque for hamstring contraction that could explain the increased susceptibility of women to ACL injuries. These same variables may contribute to the increased rate of other knee injuries in female skiers. In addition, the female skier is generally lighter and is susceptible to equipment-related lower-extremity injury from bindings with strong springs or with release capabilities that may not be appropriately set for her level of skill, weight, and age.

In contrast to the increased injury risk in women that is attributable to an increase of less severe knee sprains, the increased risk of injury in children reflects a significantly higher incidence of tibial fractures compared with the adult population. This probably reflects the fact that children use inferior equipment, or equipment that has been passed down to them that does not fit or is not properly adjusted.[14424662]

If one assumes that approximately 15 million U.S. skiers ski an average of 14 days per year and sustain approximately 2.5 injuries per 1000 skier-days, then one can assume that there are approximately 525,000 ski injuries per year. Based on current estimates, approximately 130,000 of these injuries will occur in children under the age of 16. Eighty-five thousand to 100,000 of these injuries will represent acute ACL ruptures. This rate of ACL damage has been shown to be comparable with that found in college football (Table 1).16

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TABLE 1

Rates of ACL Injury Among Published Studies

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Upper Extremity

In 1943, Watson-Jones64 first reviewed the importance of the ulnar collateral ligament in providing stability to the thumb. In 1955, Campbell8 described chronic laxity of the ulnar collateral ligament seen in Scottish gamekeepers and was the first to use the term "gamekeeper's thumb." When acute ulnar collateral ligament ruptures were identified in the skiing population, the term "skier's thumb" was coined.6 Today, a skiing fall is the most common cause of acute ulnar collateral ligament damage. Injuries to the ulnar collateral ligament comprise 8% to 10% of all ski accidents.30 They occur because of a fall with the ski pole maintained in the hand, resulting in a forced adduction and extension of the thumb (Figs. 1 and 2).645 In addition, however, the author believes that a significant component of the injury results from the fact that the skier falls past the thumb as momentum carries him or her down the hill, resulting in a severe valgus load to the metacarpophalangeal joint. The force of the fall and the valgus load applied to the joint results in a high incidence of Stener lesions in this population. Zeman et al.,66 reviewing the Aspen experience, reported a 78% incidence of Stener lesion compared with 64% reported by Stener,58 and 52% by Bowers and Hurst.5 If the patient is seen soon after the injury, the diagnosis can generally be made by palpation of the Stener lesion at the base of the thumb and by gentle stress testing.

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Figure 1

A fall on an outstretched hand with empty palm results in an abducted, extended position with stress to the radial collateral ligament but no increased load to the ulnar collateral ligament of the thumb metacarpophalangeal joint.

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Figure 2
A fall on an outstretched hand with a pole in the palm creates a radial deviation that stresses the ulnar collateral ligament of the thumb metacarpophalangeal joint.
Although a number of criteria have been described to demonstrate complete rupture of the ulnar collateral ligament, stress testing with gentle valgus load near full extension is the most cost-effective, reproducible, and clinically effective technique. A positive test is demonstrated with increased valgus opening and no demonstrated end point. Because of the high incidence of Stener lesions in the skiing population, it is advisable to treat these injuries with operative exploration and acute ligament repair using a suture anchor66 (Figs. 3 and 4). Postoperatively, the patient's hand can be placed in a low-profile (small and lightweight) thumb spica cast that allows full wrist motion. The injured skier can return to skiing and work within 1 to 2 days of the surgical repair.66

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Figure 3
A suture anchor has been placed in the proximal phalanx with 2–0 polydioxanone sutures (PDS) attached. (The arrow points to the ulnar collateral ligament, and the arrowheads point to the adductor aponeurosis, one above and one below.)

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Figure 4
The ulnar collateral ligament has been repaired using 2–0 PDS sutures employing a Kessler stitch. (The arrow points to the distal end of the ulnar collateral ligament, and arrowheads point to the reflected adductor aponeurosis.)
Prevention is based on the presumption that if the pole is not in the hand at the time the skier hits the ground, the injury will not occur. Therefore, consciously discarding the pole during a fall should be emphasized and taught. In addition, skiers should be encouraged to use poles that have a low-profile grip (one with finger grooves) without restraining devices of any kind, and to grip the pole without using straps (Fig. 5).

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Figure 5
Releasing the pole before falling allows the hand to land flat on the ground. To do that most effectively, do not place the hand through the strap, and use a low-profile grip that allows for easy release.

Shoulder

Trauma to the shoulder accounts for 4% to 11% of all ski injuries.933346265 The most common injuries are rotator cuff strains or tears, anterior glenohumeral dislocations, acromioclavicular separations, and clavicle fractures.323364 With the exception of clavicle fractures, which are increasing in frequency,30 the incidence of shoulder injuries has remained constant since 1972. In the Aspen experience, the largest subgroup of shoulder injuries was anterior dislocation, constituting approximately half of all shoulder lesions, while in other studies anterior dislocation constituted approximately 20% to 25% of all shoulder injuries.3334

The mechanism of injury is either a fall on an outstretched arm or an abduction-external rotation torque applied to the shoulder by the ski pole pulling the arm back as the skier moves past the arm on the hill. Pevny et al.,54 examining patients over the age of 40 who had first-time shoulder dislocations related to skiing, found that the incidence of concomitant rotator cuff tear was 35%, increasing to 40% in those who had a greater tuberosity fracture, and 100% in those who also had neurologic findings involving principally the axillary nerve.

Treatment of shoulder injuries in the skiing population does not differ from that of the general athletic population. Because of the high incidence of recurrence in the population under the age of 25, at our clinic we prefer to take an aggressive treatment approach using acute arthroscopic stabilization for those with first-time shoulder dislocation who are at risk for recurrence. A recurrence rate of 4% in the over-40 age group has been demonstrated, and thus, the greater concern is damage to the rotator cuff. Therefore, we treat these injuries with a sling, early motion, and early therapy, progressing to an MRI within 1 week to 10 days if substantial weakness and pain persist.54

Lower Extremity

In contrast to the upper extremity, the incidence of injury to the lower extremity has shown a dramatic improvement since the early 1970s. While the upper-body injury incidence has not changed significantly, the incidence rate for lower-extremity injuries has been reduced by 53%. This reduction is due in large part to the improvement in the rate of lower-leg injuries (injuries below the knee), which have shown an 87% reduction.30 Improved equipment probably accounts for this marked reduction in lower-leg injury.

With the advent of higher, stiffer boots that effectively bypass the ankle, ankle sprains and ankle fractures have shown a 92% reduction since the early 1970s.30 Improved bindings are responsible for the reduction in tibial fractures, as well as soft tissue contusions about the shin. As bindings have progressed from a nonrelease status through two-mode release to multimode release, both spiral fractures and nonspiral fractures of the tibia have shown reductions of more than 80% from the early 1970s (Fig. 6).

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Figure 6

Spiral fractures of the tibia have been reduced significantly because of improved binding release capabilities. However, short spiral fractures such as the one shown here remain very common. The ability of modern bindings to protect the lower leg is not purely a result of improved release capabilities. Hauser22 demonstrated the importance of a well-adjusted binding. In his study he found that 95% of all bindings tested had at least one fault, and 50% of the bindings had release levels that were at least 20% above recommended standards. When a control group of skiers was compared with a group in whom bindings had been set properly, he found that the nonadjusted control group suffered four times the incidence of binding-related injuries. This finding is consistent with the study of Ekeland et al.,14 who concluded in their 1993 review that the factors most effective in reducing lower-extremity equipment-related injuries were good ski instruction that allowed the beginning skier to move out of the novice ranks as quickly as possible, well-adjusted bindings, and self-testing of bindings. Self-testing should be performed each day that one skis.42 It is performed by first stepping into the binding and then twisting to the side to release the toe-piece under a controlled mechanism. The heel is tested by stepping into the binding and leaning forward, releasing the heel-piece. In both circumstances, the toe and heel should be able to release if properly adjusted.

Knee

The knee continues to be the most frequently injured area of the body in alpine skiing. Rates of knee injury have been reported to be between 20% and 36% of all injuries, with most knee trauma being that of injury to soft tissue.121315363 While the relative rate of knee injuries has remained fairly constant, there has been a very disturbing statistical trend toward increasing grade III ruptures to the ligamentous structures in the knee, particularly to the ACL. Johnson et al.30 reported a 228% increase in grade III sprains of the knee between 1972 and 1994. This dramatic increase was reflected in work by Järvinen et al.28 and Natri et al.,50 who demonstrated a 30-fold increase in ACL injuries through the 1980s, and by Warme et al.,63 who demonstrated a greater than 100% increase in ACL injuries in the Jackson Hole experience from 1982 to 1993. Thus, it is clear that although mild injuries to the knee in the form of grade I and grade II sprains have shown a reduction, serious knee injuries have shown an epidemic increase.

Several factors contribute to this rise. There can be little question that the ability to diagnose grade III injuries and, in particular, grade III ACL ruptures has become more consistent through the 1980s and 1990s through improved examination techniques as well as improved ancillary tests. However, this improved diagnostic capability can only explain some of the rise, but not all of it.

It appears that the same equipment improvements that helped to protect the foot, ankle, and tibia are also helping to contribute to the rise in knee injuries. Clearly, if falls in the 1990s generate the same amount of force as skiing falls in the 1970s, and the ankle and tibia are protected from those forces by modern boots and bindings, then the forces must be dissipated somewhere else. It appears that those forces are now dissipated in the knee.182332 Furthermore, although it is widely believed that a well-adjusted binding helps to protect the knee, binding adjustments are made based on the ability of the binding to resist fracture to the tibia, and not knee sprains. In addition, it seems that the release capabilities of the bindings are far too slow, even if set at the appropriate level, to resist or protect the knee and the ACL from injury.

There are three common mechanisms of injury that result in ACL rupture. Valgus-external rotation (catching an inside edge and falling forward between the skis), the boot-induced ACL injury (landing on the back of the ski with an extended knee, resulting in the boot forcing the tibia anterior as the front of the ski hits the ground) (Fig. 7), and the phantom-foot phenomenon (falling backward between the skis, catching the inside edge of the downhill ski, driving the leg into forced internal rotation) (Fig. 8). 1628 These mechanisms of injury are distinctly different from the deceleration injuries, the change-of-direction injuries, or the direct-blow injuries associated with sports such as football, basketball, and soccer. In the case of the latter, there is almost always a strong compression component to the injury, whereas in skiing, at times there can be an actual distraction of the joint at the time of ACL disruption. As a result, ACL rupture sustained through ski trauma generally results in a knee with less secondary trauma in the form of meniscal tears, grade III ligament injuries, particularly to the medial collateral ligament, and bony lesions in the form of MRI-documented bone contusions.125257

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Figure 7

When a skier contacts the ground with an extended knee and in a backward position (arrows), as the front of the ski and the front of the boot contact the ground, the tibia is levered forward with potential damage to the ACL. (Reprinted with permission from *ACL Awareness Training—Phase II,* Vermont Safety Research 1994. Illustration copyrighted by William Hamilton, 1988.)

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Figure 8

The phantom foot mechanism of injury for ACL involves leveraging of the knees and ligament by the added torque provided when the skier catches the inside edge of the downhill ski, creating a forceful internal rotation of the tibia on the femur. (Reprinted with permission from *ACL Awareness Training—Phase II,* Vermont Safety Research 1994. Illustration copyrighted by William Hamilton, 1988.)

Treatment of acute ACL disruption does not differ significantly from the treatment recommendations in other sports. However, Hunter et al.26 found that the timing of surgical intervention did not affect outcome when measured by restoration of range of motion or stability in the postoperative period. This probably reflects the fact that newer types of ACL surgeries are becoming less traumatic to the joint and the fact that the knee is less traumatized in skiing than in other sports.125257

Although surgical intervention has been shown to be an effective way of dealing with acute ACL rupture, in our center and many others, the focus has been on injury prevention. Unfortunately, to date there have been no improvements, alterations, or adjustments in ski equipment that have had a positive impact on the incidence of ACL disruption. In fact, despite the best efforts of the ski industry and the medical community, the rate of ACL injury grows steadily year after year. A ray of hope comes from the work of Ettlinger et al.,16 who developed a creative and innovative teaching program that focuses on avoiding high-risk behavior, identifying those positions and maneuvers in skiing that could result in injury, and responding appropriately when faced with a high-risk situation. When a study group of ski instructors and patrollers who went through their preseason teaching program were compared with a control group who did not have access to their protocols, a 62% reduction in ACL injury in the study population was demonstrated. However, no significant reduction was noted in a randomly selected group of employees when they were exposed to the same teaching effort.16 Therefore, the wide application of their "injury avoidance" protocol among the general skiing population remains to be proven.

In addition to the epidemic rise in grade III ligament injuries in the knee, we have also observed an alarming rise in bone injuries in the knee in the form of tibial plateau fractures. These fractures almost always involve the lateral plateau, with a fracture pattern classified as Schatzker I, II, or III (Fig. 9). The higher energy fractures (Schatzker IV through VI) are less common but are also increasing in frequency (Figs. 10 and 11). The rise in tibial plateau fractures probably reflects the same phenomenon accounting for the rise in ACL injuries, namely, increased forces transmitted to the knee. In the case of plateau fractures, the force is predominantly a valgus load resulting in compression in the lateral compartment. The fracture generally involves the anterior half of the joint with or without disruption of the medial collateral ligament. Treatment of these fractures varies, depending on the fracture pattern. Recently, an arthroscopic approach has been popularized for many of the fractures classified as Schatzker I through III; however, open reduction and internal fixation still remains the treatment of choice for Schatzker IV and V injuries. The advent of the hybrid external fixator has made management of the Schatzker VI injuries (tibial plateau fracture with dissociation of the metaphysis from the diaphyseal portion of the tibia) a bit easier with less potential for the "dead bone sandwich" frequently seen when extensive open reduction and internal fixation was attempted with bilateral screws and plates.

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Figure 9

A and B, split depression fractures are becoming more frequent in skiing, reflecting increasing forces being transmitted to the knee joint. These forces can result in plateau fractures, proximal tibia fractures, or serious ligament injury.

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Figure 10
The MRIs show a more serious high-energy type of tibial plateau injury involving both the medial (A) and lateral (B) aspects of the joint.

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Figure 11
Anteroposterior (A) and lateral (B) radiographs of the case shown in Figure 10 indicate that this is a complex type VI tibial plateau injury involving not only the plateau but the tibial shaft with complete dissociation of the plateau from a diaphysis.

Today it is clear that the modern ski boot has effectively protected the foot and ankle, the modern binding has dramatically reduced injury to the lower leg, but modern surgery continues to be the salvation of the knee. Where the breakthrough will come that results in the reduction of serious knee injuries remains to be seen. Perhaps it will be a combination of improved equipment and improved teaching in conjunction with slope management that will somehow stem the tide of severe knee injuries seen today.

Head and Spine

Head and spine injuries account for approximately 7% of alpine trauma.30 The frequency of these injuries has not changed significantly over the past 25 years, suggesting that improvements or alterations in equipment and slope maintenance probably have little effect. The mechanism of injury has been described as either a simple fall, a fall complicated by a blow with a ski or a ski pole, collision, or blunt trauma caused by chair lifts and T-bars.740 A complicating factor in many of the reports is high-speed skiing with loss of control. Simple falls are the most common injury mechanism, although collisions with immovable objects (trees, lift towers, equipment) result in the most severe, and sometimes fatal, accidents.49 The typical skier sustaining head and neck trauma is a man in his late 20s or early 30s who is an accomplished skier. This reflects the fact that men historically have been greater risk-takers than their female counterparts, and that high speed is a significant component of many of the injuries.

Because of high-profile deaths occurring secondary to skiing in the past year, there has been greater attention paid to helmets and their potential impact on injury prevention. To date, there are little data that would suggest that helmets have, in fact, reduced injury rate. Shealy et al. believed that the routine use of a helmet could result in a 60% to 80% reduction in the overall incidence of serious head injury, but they pointed out that the primary improvement would be that of mild concussion (J. E. Shealy et al., unpublished data, 1997). They believed that current helmet construction would not have a significant impact on the more high-energy injuries and feared that the routine use of helmets might change risk-taking behavior and have a net adverse effect. Because skiers under the age of 17 have twice the rate of both head injury and neck injury relative to the general population, there is some enthusiasm for the routine use of helmets in this younger age group. Although this seems intuitively obvious, the added mass of the helmet on a young child without the neck strength to sustain the load might actually put that skier at greater risk of serious neck injury in an effort to protect the head.

Fortunately, traumatic deaths from skiing are relatively infrequent, occurring at a rate of approximately 1 to 1.3 deaths per million skier-days.60 In an Austrian study, the death rate was higher (5 per million skier-days) but still constituted an injury rate lower than that found in ski touring, hiking, and rock and ice climbing.7 In a Canadian study, the death rate from skiing accidents was approximately one-tenth that of normal water sports.60

Strategies for the prevention of serious head and neck injuries and traumatic deaths have been proposed and include limiting uphill lift capacities to reduce the chances of overcrowding, grooming of runs in such a way as to avoid high-speed cruising, careful marking of all obstacles, heightened safety measures for children both on the ski slope and on the chair lift, and minimizing the angle of approach for merging trails and runs.19

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SUMMARY

Skiing is a winter sport enjoyed by approximately 200 million people worldwide. An overall injury rate of approximately 3 per 1000 skier-days means that skiing certainly is the riskiest sport undertaken by adults on a routine basis. However, the data suggest that one can anticipate years of enjoyable recreation free from injury. Many troubling injuries, particularly to the lower leg, have shown a steady decline over the past 20 to 30 years because of advances in boot design and binding capabilities. In addition, as information has been gathered regarding the importance of proper maintenance and adjustments, equipment now available can protect a skier more effectively than at any time in the past. Nevertheless, skiing continues to present inherent risks that can be minimized through the following strategies:

1. Enroll in a conditioning program before skiing that focuses on strength and endurance components particularly of the legs and back.
2. Have equipment that is compatible with the skier both from the standpoint of size and expertise.
3. Have equipment adjusted professionally.
4. Do routine testing of binding releases each day before beginning to ski.
5. Ski under control at speeds that are consistent with ability.
6. Stop skiing before fatigue becomes the limiting factor.

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Footnotes

- Neither the author nor his related institution have received any financial benefit from research in this study.
- American Orthopaedic Society for Sports Medicine

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