Current Concepts

The Skier's Knee

Michael J. Rossi, M.D., James H. Lubowitz, M.D., and Dan Guttmann, M.D.

Abstract: Knee injuries in skiers have unique epidemiology and distinct mechanisms. Conversely, evaluation and treatment of the skier's knee is similar to evaluation and treatment of knee injuries in other athletes. A greater understaning of the epidemiology and mechanisms of knee injuries in skiers may aid arthroscopic clinicians and related researchers treating or investigating knee injuries in both skiers and in other athletes. **Key Words:** Ski—Knee—Review—Injury, Mechanism—Treatment.

The history of skiing transports us to Norway. It is written that the beginning of skiing as a sport can be traced to 1843 at the Norwegian town of Tromso, that skiing as a competitive sport began in 1860, and that the first large-scale skiing contest was held in 1879 at Huseby Hill in Oslo. Skis were first used in mountaineering in Norway in 1880.[1]

However, skiing held a utilitarian purpose long before its advent as sport. Military ski competition is recorded in Norway since 1776. Moreover, pictorial representations of skiing in the form of rock carvings found at Roday in southern Norway date to 2500 to 2000 B.C.[1] Finally, and according to ski legend, the history of skiing dates to approximately 3000 B.C. when crude animal tusks were secured at the toe, with a free heel, and used for hunting as well as warfare.[2] The first ski club in the United States was founded in Berlin, New Hampshire, in 1872.[1] The United States first hosted the Winter Olympic Games in Lake Placid, New York in 1932, and the popularity of skiing increased in this country as a result.[3] In 1935, there were 10,000 skiers in this country, and by 1987, that number had increased to 14.5 million.[3] During the 1994-95 ski season, 54.6 million ski area visits were reported in the United States.[4] During the 2000-01 season, US ski resorts reported a new national record of 57.3 million visits.[5]

Snowboarders and telemark skiers share the slopes with alpine skiers, and the rate of growth in the popularity of snowboarding is notable. During the 1994-95 season, 14% of participants were snowboarders.[6] During the 2000-01 season, 28.3% of the total U.S. skier/snowboarder visits were by snowboarders (an annual rate of growth of 8.9% since the 1997-98 season).[5]

Telemark skiing, a free-heel adaptation of Nordic or cross-country technique to an alpine or backcountry slope, is also experiencing a significant increase in participation. This conclusion is based on our observations of skiers and ski school participants at the Taos, New Mexico, Ski Valley Resort. We are unable to locate published epidemiologic data regarding number of telemarkers.

EPIDEMIOLOGY: RATE OF INJURY IN SKIING

Before focusing specifically on the skier's knee, the rate of injury in skiing in general requires consideration. We first acknowledge that skiing injury statistics may be inherently flawed due to incomplete incident reporting or underreporting, incomplete skier-day

From Sun Valley Sports Medicine, Ketchum, Idaho (M.J.R.); and Taos Orthopaedic Institute, Taos, New Mexico (J.H.L., D.G.), U.S.A.

Address correspondence and reprint requests to James H. Lubowitz, M.D., Taos Orthopaedic Institute, 1219-A Gusdorf Rd, Taos, NM 87571, U.S.A.

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reporting, difficulty in defining a skier-day, and retrospective study.[7]

The rate of injury in skiing is usually expressed as the number of skiers injured per 1,000 skier days and is equivalent to the number of injuries expected among 1,000 skiers in 1 day. Other methods suggested to describe the injury rate among skiers include mean days between injuries,[8] a distance (traveled on skis) correlated injury index,[9] an equipment specific distance-correlated index,[9] a lower extremity equipment related injury rate,[10] and application of a trauma surgery injury severity score to injured body regions.[11] At the present writing, the number of skiers injured per 1,000 skier days is both the ski industry standard, and the method that best allows comparison among the published data.

Today, the rate of injury in skiing approximates 3 skiers injured per 1,000 skier days. However, at a resort with significant expert and extreme terrain, such as Taos Ski Valley, the rate approaches 4.5 (personal communication, Jim Lee, Director, Taos Ski Patrol). (The rate of fatality during skiing/snowboarding in the United States during the 2000-01 season was 0.82 per *million* skier days.[5]) If 3 skiers are injured per 1,000 skier days, the chance of an individual skier being injured in 1 day is 0.003. To express the same in whole numbers, an individual is likely to suffer 1 injury per 333 days of skiing. The average number of days skied per season is 14.[12] Thus, an individual skier is likely to be injured once in a 24-year skiing career.

The overall injury rate in skiing has actually decreased significantly over the last 60 years. A review of data collected at both Eastern and Western United States ski resorts from 1939 through 1998 shows, on average, a decrease in injury rate from 7.6 per 1,000 skier days to the current value of 3 skiers injured per 1,000 skier days.[7,10,13-18] The reasons for this decrease are speculative and have been attributed to improved individual ski equipment, specifically the ski-boot-binding interface, as well as improved ski technique and instruction, and improved resort management and safety.[2] Perhaps also, with the increased popularity of the sport, a more prudent population of skiers has joined and modified the risk-taking behavior of the original ski pioneers.

As the overall rate of injury in skiing has decreased, the rate of injury to the lower extremities in skiers has shown a like decline.[19] The rates of tibial fractures and ankle sprains have decreased dramatically due to improvements in the mechanical characteristics of the ski-boot-binding release system.[10] However, the same does not hold true regarding ski injuries specific to the knee joint.

EPIDEMIOLOGY: RATE OF KNEE INJURY IN SKIING

During the period from the 1930s through the 1970s, albeit generally reporting a rate of the ill defined "knee sprain," the rate of knee injury had remained constant and approximated 20% of all skiing injuries.[10,13-17,20-22] Since 1980, however, this rate has increased. Current data indicate that injury to the knee joint accounts for one third of all injuries to adult skiers.[7,18] (The rate of knee injury in children and adolescents approximates one half the knee injury rate in adults.[18]) Furthermore, the rate of "severe knee sprain," now well defined as a complete tear of 1 or more knee ligaments, tripled during the period from 1980 to 1995.[19]

Most authors report that the most common knee injury in skiers is a sprain of the medial collateral ligament (MCL).[7,14,22-24] From 1982-1993, at Jackson Hole, Wyoming, Ski Resort, MCL injury represented 18% of all ski injuries and 60% of all knee injuries in skiers; anterior cruciate ligament (ACL) injuries represented 16.5% of all ski injuries and 49% of all knee injuries.[7] However, other authors have reported that a complete tear of the ACL is the most common ski injury in adults.[18] Furthermore, most MCL injuries in skiers are grade I or grade II sprains[18,25] and are generally treated nonoperatively. Thus, regarding surgically significant knee injuries in skiers, injury to the ACL is paramount.

Alpine skiers, in fact, hold the notorious distinction of having among the highest rates of ACL injury of any activity or sport.[19] In the general population, the rate of ACL injury approximates 30 to 40 per 100,000 population per year.[26,27] In skiing, the rate of ACL injury approximates 50 to 70 per 100,000 skiers *per day*,[28,29] a rate matched only in American football.[30]

Athletes with ACL disruption sustain a high incidence of associated knee injuries,[31-33] and the same is true in skiers.[7,18,25,34-36] Among 315 patients treated surgically for complete ACL tears in Aspen, Colorado, 68% of the tears were combined with other injuries.[34] Combined injury to the MCL in skiers with complete disruption of the ACL has variously been reported to occur in 20% to 57% of cases.[7,25,34]

Meniscal pathology associated with complete disruption of the ACL in skiers ranges from 23% to 55%.[25,34,35] This is less than the rates of combined ACL and meniscal lesions in athletes in general, which have been reported to equal 62-65%.[35,37-39] In a direct comparison of patterns of meniscal injury associated with ACL tears in skiers versus other athletes at a single institution, 41% of skiers had meniscal tears and 63% of nonskiers had meniscal tears.[35] When limiting the study to meniscal tears requiring surgical intervention (repair or partial meniscectomy), 24% of skiers and 49% of nonskiers had meniscal tears, a significant difference.[35] In this same study, 33% of the skiers with ACL tears had a tear of the lateral meniscus and 11% had a tear of the medial meniscus. In comparison, the majority of meniscal tears in nonskiers involved the medial meniscus.

In other studies of meniscal tears associated with ACL tears in skiers, the pattern of a higher proportion of lateral in relation to medial meniscal tears is similarly reported. One author reported that 13% of skiers with torn ACLs tore their lateral meniscus and 10% tore their medial meniscus,[25] and another group found that 45% of skiers with torn ACLs tore their lateral meniscus and 10% tore their medial meniscus.[34] The ratio of increased lateral (compared with medial) meniscus tears during ACL disruption in skiers may be related to an anterolateral rotary translation of the tibia on the femur occurring at the time of injury, trapping the lateral meniscus between the posterolateral tibia and a central portion of the lateral femoral condyle.[34]

Barber[36] specifically evaluated skiers with combined ACL/MCL disruptions. In this cohort, 43% had associated torn lateral menisci, and 13% had medial meniscal tears. Other studies[40,41] report that, in athletes in general, O'Donoghue's classic terrible triad[42] of ACL/MCL/medial meniscus tear is actually not as common as the triad of ACL/MCL/lateral meniscus tear. In another study of meniscal injuries associated with acute ACL tears in skiers, the Aspen group reported that the triad of ACL/MCL/lateral meniscus tear occurred 9 times higher than the triad of ACL/MCL/medial meniscus tear.[34]

In summary, the lateral meniscus is more commonly injured than the medial meniscus in skiers with ACL tears. The proportion of lateral meniscus to medial meniscus tears is higher in skiers with ACL tears than in nonskiers. Meniscal pathology associated with complete disruption of the ACL in skiers occurs with less frequency than meniscal pathology associated with complete disruption of the ACL in nonskiers.

Little data regarding lesions of the lateral collateral ligament (LCL) in skiers have been gathered. This is likely a result of the relative infrequency of this injury in skiers. One author reported a 3% association of "lateral sprains" associated with ACL tears in skiers and noted that the injuries were "often mild".[25]

We are unaware of studies examining lesions of the posterior cruciate ligament (PCL) or the posterior lateral complex in skiers. This is likely a result of the relative infrequency of PCL injury in this population. In our experience in Taos, PCL injuries in skiers occur rarely, and usually as a result of a direct impact of the anterior tibia with a tree. In one memorable case involving this mechanism, the PCL disruption occurred in association with a comminuted fracture of the tibial diaphysis and was detected only after the tibia had healed. It is important to have a high index of suspicion for the rare PCL injury in skiers when the mechanism of injury is suggestive.

There is little data regarding knee dislocations in skiers. This is likely a result of the relative infrequency of dislocation in this population. There is a case report of a rare irreducible knee dislocation in a skier.[43] Again, a high index of suspicion is required when the presentation is suggestive.

Regarding fractures about the knee joint, 1.1% have been reported to involve the tibial plateau in skiers,[44] while other authors have reported the rate of tibial plateau fractures to be "significantly higher" than 1% of all fractures in skiers.[45] Published case reports, technical notes, and small case series describe that lateral tibial plateau fractures[2,46,47] or tibial intercondylar eminence fractures[48,49] occur commonly. Arthroscopic treatment of these lesions is an area of current investigation.[46,48,49] In our Taos experience, fractures of the tibial plateau are the most common fractures about the knee joint in skiers and range in severity from isolated lateral central depression, split or split-depression fractures, or isolated intercondylar eminence avulsions to severely comminuted bicondylar fractures with split, depression and associated extensive involvement of the tibial diaphysis.

The Female Skier

ACL injury rates differ between men and women, are sport-specific, and generally are significantly higher in women.[50] In basketball, the rate of ACL rupture in women is reported to be 4 to 8 times the rate in men.[51,52,53] Similarly, female soccer and volleyball players rupture their ACL 2 to 3 times more frequently than their male counterparts.[53,54] The causes of the gender-specific increased rate of ACL rupture in female compared with male athletes may be related to relative quadriceps muscle weakness in women, narrower intercondylar notch dimensions, increased joint laxity, or hormonal differences.[51,53]

As in other sports, the rate of ACL injuries in female skiers significantly exceeds the rate in male skiers. Among 7,300 injured skiers studied at a Utah resort, males and females sustained equal numbers of knee injuries, but regarding injuries to the ACL, the rate was double in females.[55] In a survey of ski racers in Vermont, female racers had 2 times the knee injury rate and 3 times the ACL rupture rate as male racers.[56] In contrast, in a study of 7,155 Vail ski patrollers and instructors with intact ACLs, the ACL injury rate in women (4.4 injuries per 100,000 skier days) was not significantly higher than the ACL injury rate in men (4.2 injuries per 100,000 skier days). It is hypothesized that professional ski patrollers and instructors spend a significant amount of time skiing below their ability level, and these data are therefore not applicable to the recreational skier or to the ski racer.

There are few published data regarding meniscal injury rate differences between men and women. Baker et al.[57] report that, in the general population, meniscal injuries occur more frequently in men than in women and that meniscal injuries requiring surgery occur 3 times more frequently in men than in women. In contrast, they report that, in skiers, the rate of meniscal injury in men and women is equal.

The Skier With a Disability

The majority of athletes who ski with a disability are upper-extremity or lower-extremity amputees, with a smaller representation of athletes with spinal cord injury, postpolio paralysis, or visual impairment.[58,59] Despite the differences in techniques and equipment employed by the disabled skier and despite the unique challenges with which disabled athletes are confronted, these athletes have an injury rate surprisingly similar to that of able-bodied skiers. Specifically, a rate of 2 injuries per 1,000 skier days is reported for a cohort of handicapped alpine ski racers.[58] The most common acute injury in the competitive skier with a disability is characterized as injury to the "thigh and knee" (30% of all acute injuries). The most common chronic injury in the competitive skier with a disability is to the shoulder (30% of all chronic injuries), and the second most common chronic injury is to the thigh and knee (23.3%).[59] It should be noted that disabled skiers may have "a lower exposure of injury to the lower extremity because of prosthetic devices".[59] It is hypothesized that "disabled skiers ski carefully and confine themselves to terrain appropriate to their abilities".[58]

The Telemark Skier

Confirming our Taos experience, Federiuk[60] and Tuggy[61,62] each report that telemark skiing has shown a resurgence in popularity. Telemark skiing is associated with higher injury rates than alpine skiing, approximating 9 to 11 injuries per 1,000 skier days.[61,62] Tuggy[61] reports that less experienced telemarkers incur more injuries than experienced skiers. Federiuk[60] reports that more experienced telemark skiers incur more injuries. Telemark skiers visiting lift-served areas have double the rate of injury compared with backcountry skiers.[60] This may be associated with the greater vertical distance skied in a single day by skiers in lift-served areas.

While knee injuries are the most common injury in telemarkers, with rates reported to range from 26% to 41% of all injuries,[60,61,62] the overall ACL injury rate is less than 15%.[62] Newer, plastic telemark boots appear to be a relative risk factor for significant ligamentous knee injury compared with leather or soft boots (yet protective of ankle injuries and producing an overall lower rate of injury).[60-62] Newer, releasable telemark bindings protect the knee.[60,62]

Gender differences associated with ACL tears in telemarkers resemble those in alpine skiing and in other sports: females with an acute knee injury sustain an 80% chance of ACL and/or MCL tear whereas males with an acute knee injury sustain an ACL and/or MCL tear at a rate of 46%.[62]

The Snowboarder

While the patterns of injury in snowboarding differ radically from alpine skiing, the overall injury rate is similar and approximates 4 to 6 injuries per 1,000 snowboarder days.[63,64] Upper-extremity injuries occur 20% more commonly than lower-extremity injuries in snowboarders,[64] and fractures occur more than twice as frequently as in alpine skiers.[63] Injuries specific to the knee joint occur approximately half as often in snowboarders compared with skiers and approximate 16% to 23% of all snowboarding injuries, a rate equal to the number of snowboard injuries to the foot and ankle.[63,64] Knee injuries in snowboarders are generally less severe than in alpine skiers; complete rupture of a ligament occurred in only 2 of 62 reported knee injuries in 1 series.[63] Knee injuries in snowboarders most commonly occur in novices and in those wearing hard-shell boots (the style of boots most commonly worn by novices).[63,64,65]

MECHANISM OF INJURY

A classic mechanism of ACL injury is observed in pivoting sports such as basketball and soccer; the classic mechanism generally involves sudden noncontact deceleration on a planted foot with a twisting (valgus/external rotation) or hyperextension of the knee.[39,66] ACL injuries in skiers are occasionally of the classic mechanism of injury, usually in association with a hyperextension moment.[19,67,68] In most cases, however, when the dynamic balance of the alpine skier is disturbed, the tibia is forced anterior with respect to the femur.[67] When this occurs, various mechanisms of ACL disruption may result as body parts accelerate or rotate in diverse directions and at diverse magnitudes about the center of mass.

The "boot-induced" mechanism (Fig 1) is a "big bump, flat landing" syndrome.[19,69] On landing from a jump, if off balance, the tails of the ski may strike the snow first. The ground reaction force drives the ski tips downward and the boot applies a "passive anterior drawer load" to the tibia resulting in strain and eventual rupture of the ACL.

The "phantom-foot" mechanism (Fig 2) is so named "because this injury involves the tail of the ski, a lever that points in a direction opposite that of the human foot".[69] An out-of-control skier assumes an undesirable position with the center of gravity shifting backward relative to the feet. In ski jargon, this is commonly known as being in the "back seat." The tail of the ski acts as a lever: as the tail carves into the snow, the ski accelerates forward causing anterior translation of the tibia. Rather than fall backward, the skier attempts to recover with a violent contraction of the quadriceps resulting in strain and eventual rupture of the ACL. Competitive skiers tend to experience this mechanism because of their relatively greater quadriceps strength and aggressiveness when attempting to regain balance.[69] (There is debate, however, as to the validity of the quadriceps hypothesis because it has been shown that quadriceps contraction at greater than 50° of knee flexion does not lead to ACL strain.[70,71] In fact, the quadriceps force may protect the ACL during anterior tibial translation. A cadaveric study showed quadriceps loading at 30° of knee flexion actually increases the ultimate load to ACL failure compared with controls.[72] In addition, co-contraction of the hamstrings will lessen the ACL strain associated with quadriceps forces at all angles of knee flexion.[70])

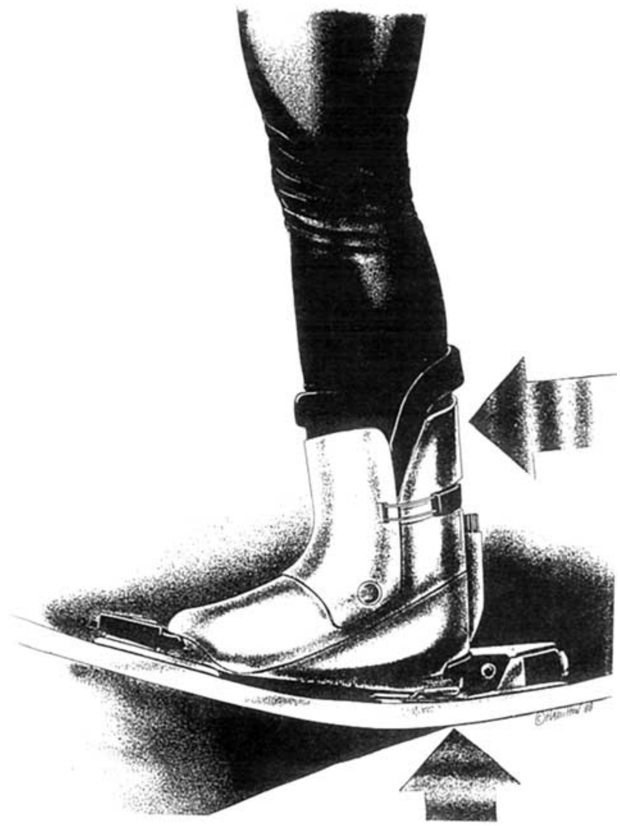

FIGURE 1. The boot-induced mechanism: If a skier lands from a jump such that the tails of the ski strike the snow first, the ground reaction force drives the ski tips downward. The boot applies a "passive anterior drawer load" to the tibia. (Reprinted with permission from *ACL Awareness Training—Phase II.* © 1994 by Vermont Safety Research. Illustration © 1988 by William Hamilton.)

In theory, both the boot-induced and phantom foot mechanisms involve a pure posterior to anterior force (on the tibia relative to the femur). This pure translational force (absent the rotational forces associated with a classic mechanism), may partly explain the relative decreased incidence of meniscal pathology associated with ACL disruption in skiers as opposed to nonskiers.[73]

A "classic" mechanism of ACL disruption in the alpine skier does resemble the mechanism seen during pivoting sports and, additionally, is associated with hyperextension. The classic mechanism in skiers occurs when the body moves forward relative to the skis leading to a severe anterior bending movement about the knee.[19,67,68] When associated with a torsional moment, this mechanism results in ACL disruption as in basketball or soccer. It is thought that this mechanism

FIGURE 2. The phantom-foot mechanism: If a skier assumes the undesirable "back seat" position, the tail of the ski carves into the snow and accelerates forward. The tail of the ski acts as a lever pointing opposite to the foot (the phantom-foot), producing anterior translation of the tibia. (Reprinted with permission from *ACL Awareness Training—Phase II.* © 1994 by Vermont Safety Research. Illustration © 1988 by William Hamilton.)

occurs most commonly in the recreational skier as opposed to the competitive racer.[67]

Finally, a rare mechanism of ACL disruption is knee hyperflexion.[74] A case report[75] describes a female beginner skier who sustained bilateral ACL tears while falling backward, experiencing bilateral internal tibial rotation and hyperflexion of the knees. An in vitro cadaveric analysis determined that application of internal tibial torque to a fully extended or flexed knee represents the greatest potential for ACL injury from falls during skiing.[76]

An assay using patient interviews to evaluate ACL disruption mechanism in skiers[77] revealed an equal incidence of the "classic" mechanism and the "phantom foot mechanism." Patients did not describe the "boot-induced mechanism."

Magnetic resonance imaging analysis of bone bruises associated with ACL injuries may provide insight with regard to mechanism in both skiers and nonskiers.[78] In nonskiers, 83% have bone bruises on the lateral femoral condyle and 78% on the posterolateral tibial rim suggesting valgus forces applied to a weight-bearing and fixed foot. In skiers, however, only 40% had bone bruises on the lateral femoral condyle, suggesting diminished valgus stress and diminished plantar loading. In addition, 81% of these same skiers had lateral tibial plateau bone bruises located (predominantly) on the posterior tibial rim, suggesting that ACL injuries in skiers occur in a position of significant knee flexion. The high rate of posterior tibial lesions, coupled with a lower rate of lateral femoral condylar lesions, may imply marked (internal or external) rotation of the tibia at the time of injury. This is consistent with the extended lever arm, the ski.

The magnetic resonance imaging evidence, as thus interpreted, suggests an alternative explanation for the relative decreased incidence of meniscal pathology associated with ACL disruption in skiers as opposed to nonskiers. In contrast to the theoretically pure posterior-to-anterior translational force (absent rotational forces), associated with the boot-induced and phantom foot mechanisms as cited above, an alternative hypothesis for the relative decreased incidence of meniscal pathology associated with ACL disruption in skiers is the absence of plantar loading (even in the context of a violent rotational moment).[78] It is possible that both theories may apply, as different mechanisms may result in the same outcome (and for different reasons).

The mechanism of injury in snowboarders is different from that in skiers consistent with the radically different equipment. A snowboarder concentrates most of his or her weight on the forward foot, and 91% of lower-extremity injuries in both regular (left foot forward) and "goofy foot" (right foot forward) boarders involve the forward limb.[63] Injury is caused mainly by a direct blow to the limb (63% of cases).[65] Specifically, falls onto the slope are the most common mechanism for lower extremity knee and ankle injuries in snowboarders.[63] As a direct result of both feet being fixed to the same surface—the board—the torsional mechanisms found in alpine skiing are uncommon in snowboarding.[65]

The mechanism of injury in Telemark skiing has not been studied in detail but is thought to be similar to alpine skiing. However, telemark skiers use a detached heel binding, allowing a greater degree of freedom of lower extremity movement relative to the extended lever arm of the ski. This appears to protect the knee joint from radical torsional moments.[62]

EQUIPMENT-RELATED INJURIES

In alpine skiing, the boot is attached to the ski by a binding. The binding protects a skier from injury through 2 crucial but opposing functions.[79] First, the binding fixes the boot to the ski preventing unintentional release in difficult conditions or dangerous terrain. Second, the binding releases by design when extreme forces are transmitted from the extended lever arm, the ski, to protect the leg from experiencing pathological forces or moments. The binding releases at the toe as a result of twisting (side-to-side moments) or at the heel in response to extreme forward lean.[80]

A preset binding release value or DIN (Deutsches Institut für Normung) is standardized so as not to exceed a force estimated necessary to fracture the shaft of the tibia and based upon variables of age, gender, body weight, and skier ability. Prevention of injury specific to the knee joint is not considered in the calculation of the DIN. While binding-release systems have decreased the incidence of tibial fractures, ankle fractures, and ankle sprains, there is no evidence that the binding-release systems protect against severe knee sprains.[79] Nevertheless, most knee ligament ruptures in skiers occur when the bindings release late or not at all (T. Quigley Peterson, M.D., Director, Taos Mogul Medicine Clinic, personal communication). As combined ACL/MCL injuries in skiers typically involve forward and twisting-type falls,[81] conventional 2-mode release bindings should theoretically protect against this mechanism of injury.

Johnson et al.[10] report that 80% of lower-extremity injuries are lower-extremity equipment-related (LEER) injuries, most are knee injuries, and 50% of involved skiers have their bindings adjusted to too high a setting relative to their calculated DIN. Beginners are at 6 times greater risk than experts for LEER injury as a result of improperly adjusted bindings.[82] It is reported that in children, 50% of bindings are more than 5 years old, and in 40% of bindings, the DIN is not properly adjusted.[83] In addition, elite skiers and competitive ski racers are at increased injury risk as they may inappropriately "crank up" the DIN to prevent premature binding release resulting in a disqualifying fall.[67] It is recommended that adequately trained personnel perform accurate adjustments of ski bindings using a testing device at regular intervals.[79]

While bindings are the primary area of equipment-related ski injury, other changes in equipment design have significance. In the modern era, the transition from leather ski boots to a higher, more rigid boot with forward lean may be responsible for the increased rate of knee ligament rupture in skiers.[18] Increased turning characteristics of modern skis may also contribute to an increased rate of knee ligament injury.[18] It is indeterminate whether the most contemporary "shaped ski" designs, with even greater turning characteristics, will increase the rate of knee ligament injury or, because of a concomitant decrease in ski length (decreased lever arm), knee ligament injury rates will remain constant or even decrease.

PHYSIOLOGY

Physiology, specifically athletic training and human performance, may have direct implications regarding the skier's knee. The current literature is of a basic science nature. For consideration: as much as 60% of metabolism is anaerobic in a competitive alpine ski race and up to 50% of glycogen stores may be depleted after a single day of skiing, significantly reducing knee extensor strength.[84-86] In a cohort of elite male skiers, knee flexion and extension peak torques dropped approximately 15% over the course of a season.[87] In a study evaluating instrumented knee laxity (KT-1000) before and after 2 vigorous training runs, ski racers were compared with a control group of recreational skiers.[88] Significant increases in anterior laxity were seen in the racers (ranging from 2.0 to 5.0 mm) compared with no significant change in the control group. Finally, studies of muscular activity patterns in competitive ski racers reveal a marked predominance of eccentric over concentric muscle action.[89-91] Future study may elucidate the clinical relevance of this data.

PREVENTION

Properly adjusted bindings clearly reduce ski injuries.[17,92,93] In addition, an "ACL awareness" video and training program reduced knee sprains in professional ski patrollers and instructors by 62% compared with controls.[19] This program focused on prevention of injury by training skiers how to respond or react when they find themselves in the typical mechanism(s) of a high-risk fall. A different video and education program reduced injury, notably injury due to fall or collision, by 30% in nonprofessional skiers. The focus was on equipment, particularly bindings, as well as behavior and instruction.[94]

PATIENT EVALUATION

Published literature regarding history, physical examination, and imaging evaluation of the skier's knee does not reveal significant or notable differences compared with knee evaluation of nonskiers. Based on our review, the mechanism of injury and timing or absence of binding release may be revealing. Concomitant injury must always be considered.

TREATMENT

While published recommendations regarding treatment of the skier's knee do not deviate significantly from treatment recommendations for nonskiers, a few publications specific to treatment of knee injuries in skiers are notable. In a skiing population, ACL reconstructed knees had half the relative injury risk as compared with unreconstructed (ACL-deficient) knees.[95] Compared with uninjured knees, the relative risk of injury was 3.1 times greater for the ACL reconstructed knees and 6.2 times greater for the unreconstructed knees. The severity of injury also differed between ACL reconstructed and unreconstructed (ACL-deficient) knees in this cohort. Injury severity, as measured by need for surgical intervention, was decreased by one third in the ACL reconstructed subgroup compared with the unreconstructed subgroup.

In addition, the ACL reconstructed subgroup was stratified by graft choice.[95] Knees reconstructed with bone–patellar tendon–bone grafts were significantly less likely to rerupture the ACL (when knee injury occurred) compared with knees reconstructed with hamstring tendon grafts.

Also specific to treatment of knee injuries in skiers is a study asserting that early reconstruction of ACL injury does not increase the incidence of arthrofibrosis.[96] Motion (and stability) is noted to be equal in skiers having early ($<$48 hours after injury) ACL reconstruction and delayed ($>$3 weeks after injury) ACL reconstruction using bone–patellar tendon–bone grafts. An aggressive postoperative physical therapy protocol is emphasized.

Functional knee bracing is shown to specifically increase afferent input (proprioception) in expert downhill skiers.[97] Proper fit of functional knee braces is essential; septic arthritis as a result of skin irritation and maceration due to a poorly fitting functional knee brace has been described in a skier after an ACL reconstruction.[98]

SUMMARY

Knee injuries in skiers have unique and specific epidemiology and mechanisms of injury. Evaluation and treatment of the skier's knee is, at present, similar to evaluation and treatment of knee injuries in athletes in general. A greater understanding of the epidemiology and mechanisms of knee injuries in skiers may aid arthroscopic clinicians and related researchers treating or investigating knee injuries in both skiers and nonskiers.

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