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Anterior Cruciate Ligament Injuries in Skiers: Current Concepts

Lesiones del ligamento cruzado anterior en esquiadores: Conceptos actuales

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Abstract

Skiing is an individual sport with an injury rate of 1.84 per 1,000 skier days among the general population. Anterior cruciate ligament (ACL) tears are among the most common injuries in skiers, with a rate of 5 per 100 skiers per season at a competitive level, because of the great demand placed on the knees. Their treatment is a challenge for orthopedic surgeons. A review of the literature was carried out regarding injury mechanisms, treatment, prevention, rehabilitation, and the use of bracing in the return to sports. The classic injury mechanisms in amateur and competitive skiers are described. Most ACL injuries require surgical resolution, with reconstruction using autologous bone-patellar tendon-bone graft, except in older patients or those with open physis, who must receive an autologous semitendinosus-gracilis graft. Prevention and rehabilitation are based on improving strength and neuromuscular control of the dynamic knee stabilizers, implementing specific programs, evaluating the sport movements, and performing neuromuscular control tests. Suitable functional bracings are recommended in patients undergoing ACL reconstruction. ACL injuries in competitive-level skiers are common, and their management is specific and multidisciplinary. The choice of graft and rehabilitation type is critical to resume skiing. Level of evidence: V.

Keywords
- skiing
- knee injuries
- anterior cruciate ligament
- treatment
- prevention
- knee bracing

Resumen

El esquí es un deporte individual con una tasa de lesiones de 1,84 por 1.000 días esquiador en la población general. Las roturas del ligamento cruzado anterior (LCA) son algunas de las más comunes, llegando a una tasa de 5 por cada 100 esquiadores por temporada a nivel competitivo, debido a la gran exigencia a la que se encuentran sometidas las rodillas. Lo anterior presenta un desafío para el traumatólogo a la hora de plantear un manejo. Se realizó una revisión de la literatura respecto de los mecanismos

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de lesión, tratamiento, prevención, rehabilitación y uso de órtesis en el retorno deportivo. Se describen los mecanismos clásicos de lesión en esquiadores amateurs y competitivos. La mayoría de las lesiones de LCA son de resolución quirúrgica, en que la recomendación de reconstrucción debe ser con injerto autólogo de hueso-tendón patelar-hueso, salvo en los pacientes mayores o en pacientes con fisis abierta, en los que se recomienda el uso de injerto autólogo de semitendinoso-gracilis. La prevención y rehabilitación se basan en mejorar la fuerza y el control neuromuscular de los estabilizadores dinámicos de la rodilla, implementándose programas específicos, evaluación del gesto deportivo, y pruebas de control neuromuscular. Se recomienda el uso de órtesis funcionales adecuadas en los pacientes sometidos a reconstrucción del LCA. Las lesiones de LCA en esquiadores de nivel competitivo son habituales, de manejo específico y multidisciplinario. La elección del injerto y del tipo de rehabilitación son fundamentales en el retorno deportivo del esquiador. Nivel de evidencia: V.

Palabras Clave
- esquí
- lesiones de rodilla
- ligamento cruzado anterior
- tratamiento
- prevención
- órtesis de rodilla

Introduction

Skiing is a sport practiced worldwide by approximately 200 million people every year. In Chile, the practice of skiing is increasing, with 19 ski centers across the country. In 2017, Asociación de Centros de Esquí de Chile (Association of Ski Centers of Chile, ACESKI, in Spanish)[1] reported 1,003,269 skier days nationwide. At the same time, accident reports in these centers revealed an average rate of 1.84 injuries per 1,000 skier days; 81% of the accidents involved intermediate or beginner skiers.[1]

In Chile, competitive skiing has three main disciplines: alpine skiing (in which the goal is to complete sloped turns marked with sticks in the shortest time); freestyle skiing (a recent discipline featuring more radical, acrobatic events); and cross-country skiing (an against-the-clock competition, mostly on long-distance, flat trails).

Alpine skiing is by far the most popular discipline in Chile, and it has the longest competitive tradition worldwide. There are four alpine skiing modalities, ranging from slalom, the most technical one, with trail markers at a short distance and quick turns, to downhill, in which the markers are at a much greater distance so the skis are constantly pointing downwards, resulting in speeds of up to 140 km/h. The giant slalom and the super giant slalom (super-G) are intermediate race modalities with increased turn width and higher skier speed.

Freestyle skiing is subdivided into three disciplines: ski cross, a race with four athletes running simultaneously on a trail with jumps and banked turns, similar to motocross; slopestyle, in which athletes must perform tricks in a series of consecutive jumps and metal rails; and big air, consisting in a single large jump to perform technically difficult stunts. Slopestyle and big air winners are those with the highest score awarded by judges.

Skiing as a sport has evolved over time, with design and technological improvements to skis, bindings, and boots to increase performance levels and safety.

Injuries can be classified per missed practice days; as such, injuries are classified as mild, minimal, regular, moderate, and severe when the skier misses 0, 1 to 3, 4 to 7, 8 to 28, and over 28 days of practice respectively.[2]

Vidal et al.[3] evaluated injuries occurring in a single ski resort from 1992 to 2015, revealing a rate of 3.5 injuries per 1,000 skier days, with no significant variation over the years.

However, the injury rates are higher at a competitive level. The International Ski Federation (FIS) reports injuries as described by the competitors through surveys at the end of the season since 2006. A total of 1,083 injuries were recorded in World Cups from 2006 to 2019. In total, 41.3% of these injuries involved the knee, and 61.7% of knee injuries were deemed severe.[4] From all World Cup knee injuries, 168 (37.6%) involved the anterior cruciate ligament (ACL), resulting in an absolute risk of 5 ACL injuries per 100 skiers per season.[5]

During the last Winter Olympics in PyeongChang, China, 2018, 376 injuries were recorded, resulting in 12.9 injuries per 100 athletes. In total, 33% of these injuries made it impossible for the athlete to carry out activities for 1 or more days, and 7% of them were considered severe. Out of the 49 injuries resulting in 7 or more missed days, 12 were reported as ligament injuries, representing 24.5% of all lesions.[6]

When comparing these figures with those of other sports, soccer has 7.7 injuries per 1,000 play hours, reaching 28.1 injuries per 1,000 hours during matches. Regarding severe injuries, this number drops to 0.7 per 1,000 hours, with 0.11 per 1,000 hours for ACL injuries.[7] The high incidence of ACL injuries in skiers, especially high-performance athletes, is something of which we must be aware.

Mechanisms for ACL Injury

The classic mechanisms for ACL injury in amateur skiers were described by Ettlinger et al.[8] in 1995, who identified two main mechanisms at a video analysis:

Phantom foot: this is the most frequent mechanism, common in beginner skiers who try to sit down when losing control. A deep knee flexion is generated by weight loading

on the inner edge of the supporting foot. This traps the edge in the snow, resulting in an internal tibial rotation which leads to the injury (►**Figure 1**).

Boot-induced injury: it occurs when the skier loses balance backwards and supports their weight on the ski tail; when the skier tries to extend the knees to regain balance, an anterior tibial translation is generated, resulting in an ACL injury (►**Figure 2**).

Bere et al.[9] described three classic mechanisms in competitive-level skiers based on a video analysis of falls during World Cups from 2006 to 2009.

Landing back-weighted injury: this mechanism is similar to the boot-induced injury. The skier loses balance when jumping, landing on ski tails. This generates two forces, one for anterior tibial translation and another for femorotibial compression (►**Figure 3**).

Slip-catch: this is the most common mechanism. The ski loses grip on the snow at the outside aspect of the turn, and it separates from the skier. The skier extends the knee to regain grip, resulting in a sudden internal flexion and rotation of the knee (►**Figure 4**).

Dynamic snowplow: it occurs when the skier loses balance and weight loading occurs on the inside aspect of the turn. The outer part of the ski rides away from the skier, forcing the inner ski to change its support to the inner edge, being trapped on the snow and forcing an internal rotation and/or valgus deformity (►**Figure 5**).

These last two mechanisms represent 65% of all ACL injuries in competitive skiers.[9]

As previously described, valgus deformity and/or internal rotation are the main mechanisms for ACL injury.

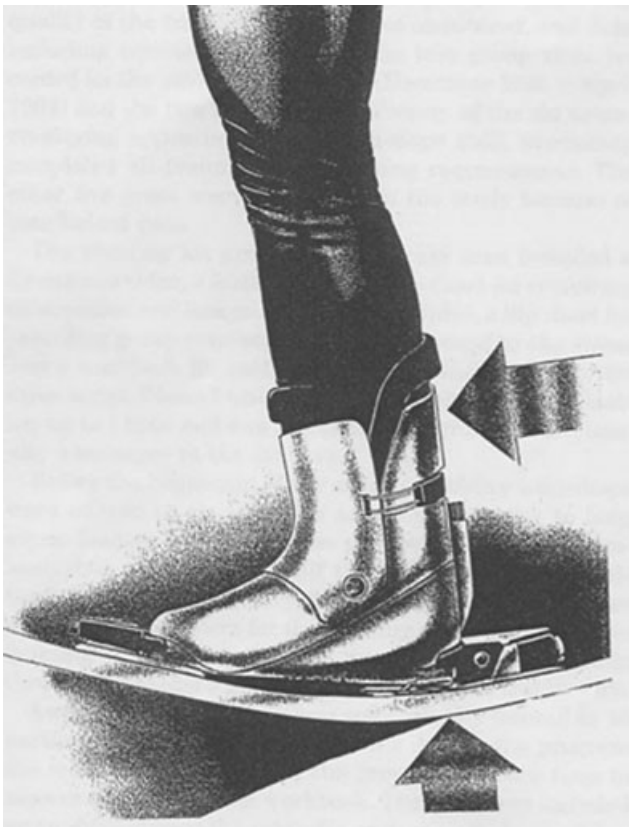

Fig. 2 When the skier loses balance, weight is carried back, resulting in knee extension. This transfers forces from the boot, generating an anterior tibial translation that leads to the injury.

Fig. 1 The skier loses balance on the skis, resulting in deep knee flexion, weight loading on the inner edge, and ski trapping in the snow, leading to an internal tibial rotation that causes the injury.

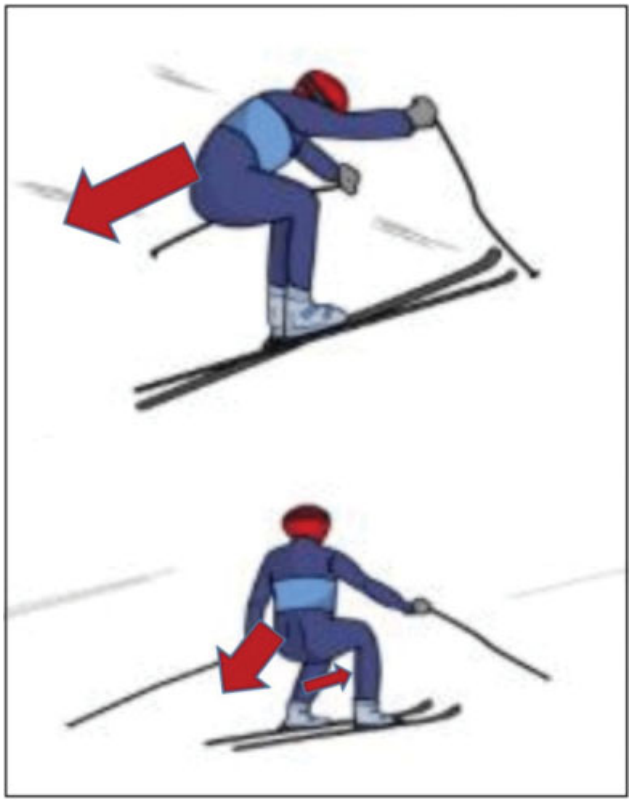

Fig. 3 The skier lands from the jump with a backward balance. A sudden anterior drawer is generated along with a femoral-tibial compression force, resulting in anterior cruciate ligament injury.

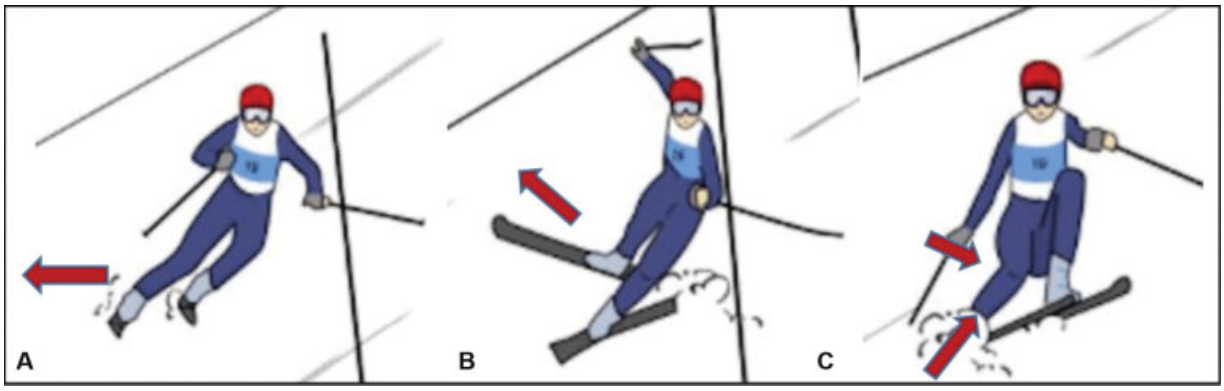

Fig. 4 (A) The outer ski loses grip. (B) Fall towards the inside aspect of the turn; the outer ski loses contact with the snow, and the skier extends the knee to regain grip of the ski in the snow. (C) The contact between the outer ski and the snow generates sudden internal flexion and rotation of the tibia.

Biomechanical torque studies show that the ACL is more vulnerable to injury when the knee is in deep flexion or extension, as occurs in this group of athletes.

ACL Treatment in Skiers

Considering all the aforementioned features regarding skiing, the current literature supports ACL reconstruction (ACL-R) in all high-performance athletes and patients with clinical instability who intend to resume its practice.

Before deciding which graft to use, the variables that will affect the patient's morbidity, rehabilitation, and return to sports, in addition to the risk of graft re-rupture, must be considered. These include the biomechanical properties of the graft, the age and gender of the patient, and the level of competitiveness.

Multiple studies tried to answer which is the best graft for each individual patient and sport, but very few are focused only on winter sports.

Initially, it is critical to clarify the significant difference in resistance and survival between an allograft and an autograft in young athletes. In a 10-year follow-up study, Bottoni et al.[10] concluded that the failure rate for allografts is 3-fold higher. Similarly, Maletis et al.[11] concluded that greater allograft processing and longer follow-up period increase the risk of revision of the ACL-R. Therefore, reconstruction using an

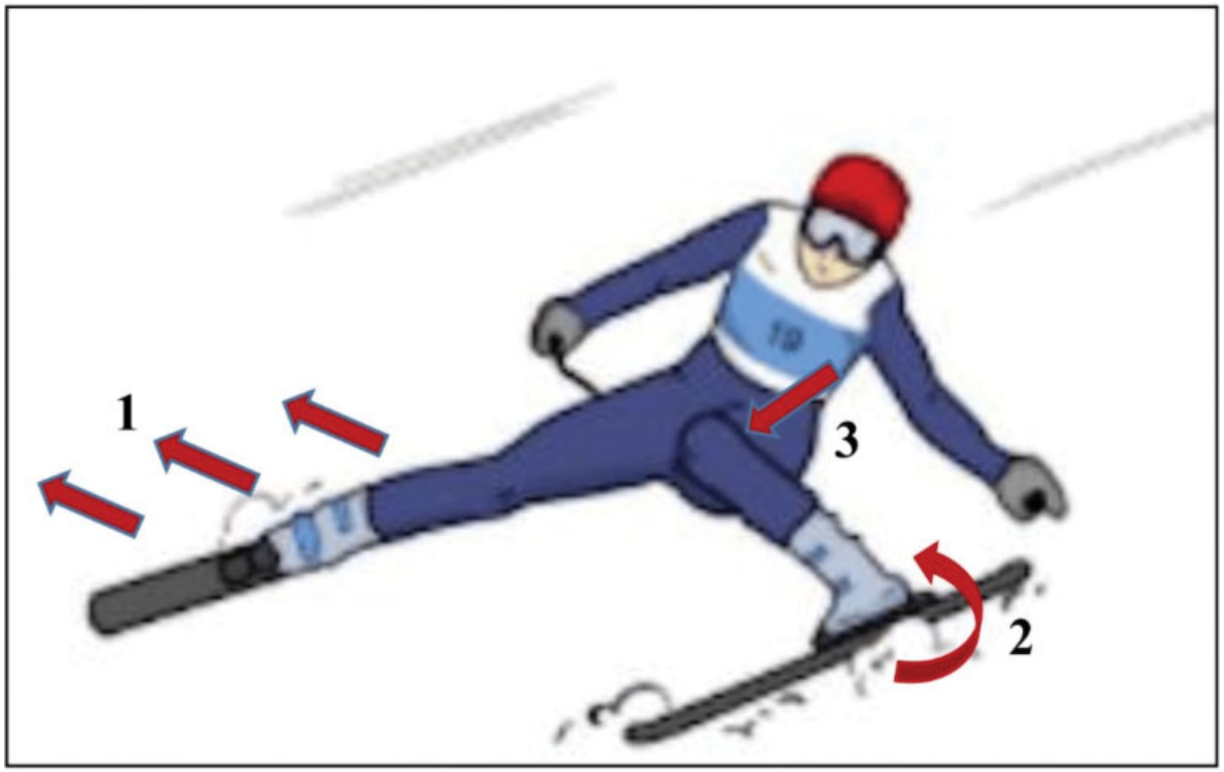

Fig. 5 1) The outer ski loses pressure and moves away from the skier. 2) The inner ski is forced to change the support to the inner edge. 3) The knee inside the turn is forced into valgus and internal rotation.

autograft is recommended in ACL tears in young athletes, especially those in high-performance levels.

It should be considered that the hamstring muscles act as ACL agonists to resist anterior tibial translation,[12,13] which is consistent with the study by Behrens et al.,[14] who demonstrated that impaired hamstring neuromuscular function and acute fatigue result in increased tibial translation and ACL tension.

Skiers perform repeated bidirectional turns with strong eccentric muscle contractions, involving peak levels of neuromuscular activity in the lower limbs.[15,16] To meet these demands, elite skiers exhibit high strength levels in the hamstring and quadriceps muscles, a high resistance ratio (hamstring/quadriceps ratio), and a marked level of strength symmetry in both extremities.[17,18]

Reconstruction with semitendinosus-gracilis (STG) autograft lengthens the electromechanical delay for knee flexion, which can affect stability when the direction and load change.[19] Hiemstra et al.[20] demonstrated a significant hamstring strength deficit in subjects submitted to ACL-R with semitendinosus autografts compared to controls. Jordan et al.[21] concluded that maximum strength and burst strength for hamstring and quadriceps muscles are important determinants to evaluate skiers submitted to ACL-R.

In a prospective randomized trial of patients submitted to ACL-R with STG and bone-tendon-bone (BTB) grafts, Marder et al.[22] revealed that the only difference between groups was the significantly greater decrease in hamstring strength in isokinetic tests performed by recipients of STG grafts. Similarly, Aglietti et al.[23] compared reconstructions with STG versus BTB grafts, and reported a significantly higher return rate to high-performance sports after ACL-R with BTB grafts. Likewise, Oates et al.[24] showed that both grafts have similar mean values on the KT-1000 (Medmetric Co., San Diego, CA, US) arthrometer, and that the rates of future injury and reoperation have no significant difference. However, six injuries in knees receiving STG tendon grafts were graft ruptures, while none of the knees treated with BTB grafts suffered reruptures; as such, these authors recommended BTB grafts as the standard for reconstruction in elite skiers.

In 2020, Ekeland et al.[25] reviewed a total of 711 graft failures with secondary ACL-R in a cohort of 14,201 subjects, including 19.8% of skiers. The revision rate for BTB grafts was of 2.7% compared to 6.8% for STG grafts ($p < 0.001$); the risk of graft revision was 1.8-fold higher for STG than for BTB grafts ($p < 0.001$), and 2.8-fold higher for subjects aged $\leq$ 18 years ($p < 0.001$).

Accordingly, young patients with high athletic performance should be submitted to reconstruction with patellar tendon grafts. In older patients with lower ACL demand but who wish to continue participating in risky activities, reconstruction should be performed using STG grafts, with no gender-related differences. In patients with open physis, to avoid instability-associated injuries, the recommendation is ACL-R with STG graft to prevent early physeal closure, considering the high risk of re-ruptures in this age group, despite an adequate surgical technique.[24,25]

Injury Prevention and Sports Return Programs

Since the early 1990s, it has been postulated that certain training programs focused on improvement of strength and neuromuscular control of active knee stabilizers could be effective in reducing the risk of injury. Van Mechelen et al.[26] postulated a "Sports Injury Prevention Sequence," in which the study of the incidence rate of injuries and injury mechanisms, along with prevention programs and an evaluation of the outcomes, create a virtuous circle to tailor prevention measures to the new challenges presented by sports;[27] however, it is often difficult to prove its effectiveness.[28] Based on this model, multiple programs have tried to demonstrate their effectiveness in preventing ACL injuries.

In 2015, Donnell-Fink et al.[29] conducted a meta-analysis to compare 12 ACL injury prevention programs totaling over 17 thousand athletes (not including skiers). The authors concluded that these programs would decrease the risk of ACL injury by 51%.[29] In 1995, Ettlinger et al.[8] published the first results of an injury prevention program from the Ski Safety Research Group, in Vermont, US. This study showed a 63% decrease in the incidence rate of ACL injuries after implementing a training and education program for on-slope staff and patrols working at a ski resort.

Currently, there is a consensus that specific training programs, either for prevention or prior to sports reintegration, should be aimed at increasing the strength and neuromuscular control of dynamic knee stabilizers.[30,31] Fort-Vanmeerhaeghe et al.[32] suggest concentrating on acquiring seven fundamental movement skills: dynamic stability (mainly associated with disturbances and changes of direction); resistance to fatigue; coordination; speed/agility; strength; plyometrics; and sport or discipline-specific skills. These programs must respect the principle of individuality and present clear, motivating progression criteria.

The instrumented evaluation of the sport movements and the implementation of neuromuscular control tests are useful both to design training programs focused on injury prevention and to plan the postsurgical return to sports.[33,34] These tests aim to investigate injury-predictive movements, such as dynamic valgus and functional asymmetries in lower extremities that often go unnoticed when they are not directly searched.[35] Tools, such as the Vail Sport Test (►**Figure 6**), have proven to be useful to determine the preparticipatory condition of the skier and as criteria for operated athletes to enter sports return programs.[33,36] According to the Van Mechelen et al.[26] model, these tools may also evaluate the effectiveness of prevention plans.

Today, there are multiple training plans for the prevention of injuries in skiers, specially the Skadefri/Get Set initiative of the International Olympic Committee and the Oslo Sports Trauma Research Center, which compiles series of simple exercises in three-level progressions.[37]

Bracing Use for Sports Return

To date, there is little evidence regarding the potential efficacy of functional and prophylactic bracing in skiers. However, three studies[38–40] have supported bracing in patients submitted to ACL-R.

Spitzenpfeil[38] evaluated course times on a slalom track in three elite skiers with and without braces. The skiers were asked to wear braces alternately for nine courses. The course times showed that there was no statistically significant difference related to bracing. However, skiers reported a negative experience with braces in terms of agility, speed, and uncomfortable skin pressure.

Nemth et al.[39] evaluated electromyographic changes in six expert downhill skiers using custom-designed functional bracings. All had suffered a previous ACL injury: three had undergone ACL-R, and five were positive on the Lachman test. Although there were no statistically significant differences, the authors mention that the braces changed muscle coordination and activation, potentially contributing to the stability of the injured knee. Interestingly, all participants reported feeling safer and more stable when using braces.

A prospective study by Sterret et al.,[40] published in 2006, evaluated the use of functional braces in workers of a ski resort who had undergone ACL-R. In total, 820 knees were included, 31% of which used bracings, with a follow-up time of up to 6 years. A higher risk of injury was observed in the group without braces (odds ratio [OR]: 2.7; confidence interval [CI]: 1.2 to 4.9); these subjects also presented an increased need for reoperation (OR: 3.9; CI: 1.2 to 12.3). The authors concluded that, for ACL-R patients, not wearing functional braces is an independent risk factor for a new injury, and recommended their use by these subjects. This is consistent with a 2017 review from Negrín et al.,[41] who evaluated the use of prophylactic and functional bracings in skiers, revealing a decrease in re-rupture rates in ACL-R patients with functional braces (►**Figure 7**).

Conclusion

Skiing is an individual sport with a high rate of ACL tears due to the great strain imposed on the knees. The treatment of these injuries is a challenge for orthopedic surgeons.

Most ACL injuries in skiers are treated surgically. The literature recommends using a BTB autograft for reconstruction in elite athletes, as well as in young patients who intend to maintain high performance levels, due to its lower re-rupture rate, regardless of gender. In older patients, with lower knee loading but who wish to resume a high-demand sports activity, reconstruction with an STG autograft is recommended due to the lower morbidity of the donor site. Finally, in patients with open physis, given the impossibility of BTB grafting due to the risk of physeal closure, an autologous STG graft should be used.

Regarding the prevention and rehabilitation of ACL injuries, different training programs are based on improving the strength and neuromuscular control of the dynamic stabilizers of the knee. The implementation of specific programs and the instrumented evaluation of the sporting gesture and neuromuscular control tests result in a significant decrease in the incidence of injuries.

Functional braces are recommended when skiing is resumed because they reduce the risk of re-rupture in patients submitted to ACL-R. However, braces are not recommended for skiers with no previous injuries due to the lack of a protective function.

Fig. 6 Patient performing the Vail Sport Test as an evaluation to resume the practice of sports.

Fig. 7 Competitive skier patient undergoing anterior cruciate ligament reconstruction and demonstrating the use of functional knee bracing.

Conflict of Interests

Dr. Negrín reports personal fees from Zimmer Biomet and from Smith & Nephew apart from this study. The remaining authors have no conflict of interests to declare.

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