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State of the Art

Multiligament knee injuries in winter sports athletes

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ABSTRACT

Multiligament knee injuries (MLKIs) are severe injuries that involve complete or partial tear to multiple ligaments of the knee, such as the cruciate ligaments, collateral ligaments, as well as structures such as the posteromedial and posterolateral corners. These injuries often occur as a result of high-energy trauma in motor vehicle accidents, but can also occur during sports activities such as a fall or collision while skiing or snowboarding. Diagnosis of an MLKI can be challenging due to the multifaceted nature of these injuries, and a comprehensive evaluation, including a thorough history, physical examination, and imaging studies, is necessary. Imaging methods, such as plain and stress radiographs and magnetic resonance imaging, are often used to confirm the diagnosis and assist in the establishment of a treatment plan. Treatment of MLKIs commonly involves surgical repair or reconstruction of torn ligaments and capsular structures, followed by lengthy rehabilitation focused on mobility, strength, and improving knee function. Return to sport is a concern, especially for those with many ligaments torn and those involving both cruciate ligaments and/or those involving the posterolateral corner. Prevention of MLKIs in skiing and snowboarding is important, and proper technique, equipment, risk awareness, and strengthening exercises can help reduce the risk of injury. While much is known about knee injuries in skiers, further research is needed to better understand MLKIs in ski and snowboard athletes, including the incidence, optimal management, and return to sport rates.

Introduction

Multiligament knee injuries (MLKIs), with or without concomitant knee dislocations, are devastating injuries that can occur in the setting of both high-energy traumas and low-velocity torsional injuries.[1] The mechanical forces as well as environmental factors found in skiing and snowboarding can lead to optimal conditions to cause such an injury. MLKIs are rare, reported to be around 0.02% to 0.20% of all orthopedic injuries[2]; however, they may be underestimated because of the complexity and often challenging diagnosis.

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By definition, an MLKI is recognized as a tear of at least 2 of the 4 major knee ligament structures: the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), posteromedial corner (PMC), and posterolateral corner (PLC).[3] These injuries are often associated with impairment to the neurovascular structures of the lower limb as well as complex meniscal tears and chondral injuries, which can be challenging to treat and can influence the final outcomes of surgery.[4] Furthermore, recent literature has demonstrated that these types of injuries can be associated with periarticular fractures or extensor mechanism disruptions, leading to worse outcomes.[5,6] Additionally, these injuries have demonstrated the ability to be highly debilitating and career-ending for competitive athletes and weekend warriors.

Despite the severity of these injuries and their associated concomitant pathologies, recent literature demonstrates promising results for return to play as advancements in the management of these conditions continue to improve.[7–10] In many cases, for patients to reach their preinjury level, anatomical surgical reconstruction and early rehabilitation are key in promoting optimal outcomes and return to sport following MLKI.[11] This review article aims to display the epidemiology of MLKI as it relates to skiing and snowboarding, diagnosis, treatment plans, the outcomes of MLKI reconstruction, and the return to sport timeline following these injuries.

Epidemiology relating to skiing/snowboarding in MLKI

Downhill skiing and snowboarding are 2 of the most popular winter sports in the world, with nearly 61 million skier/snowboarder visits within the United States alone during the 2021-2022 season.[12] However, these sports do have a reputation for a high risk of injury.[13] Literature published before 1975 reports that the rate of injury for alpine skiers ranged from 5.0 to 7.6 per 1000 skier days; however, as the safety of skiing and ski-boot-binding systems improved, the rate decreased to 2.0 injuries per 1000 skier days by the mid-1990s.[14–16] While this improvement was especially successful in decreasing the prevalence of tibial shaft fractures, the overall rate of ACL injuries increased 280%,[14] suggesting that knee ligament injuries remain a prominent concern for skiers. In snowboarding, while the rate of overall knee injuries may be lower, the prevalence of knee ligament injuries has increased in more recent years,[17] the most common of these arising from flat surface landings.[17–20]

The rates of ACL injury in alpine skiing are notably elevated in the literature,[13,15,16,21,22] with the incidence reported as 0.23 ACL injuries per 1000 skier days.[21,23] This elevated risk seems to be independent of skill level, as the most frequent injuries in all comers, and specifically high-performing skiers, are knee ligament injuries for both males and females.[24] While there are data demonstrating an increased prevalence of ACL injuries in females, more recent data regarding MLKI did not delineate any significant differences concerning sex, age, body mass index, physical fitness, or skill level between MLKI and isolated ACL skiing injuries.[15]

MLKIs associated with knee dislocations are of particular concern in skiing and snowboarding as a result of the high-energy nature of both sports. Sabesan et al[25] reported that skiing has the highest incidence of knee dislocation among assessed extreme sports. One epidemiological study analyzing snow sports injuries found knee dislocations to be the most common serious injury among skiers, with an incidence of 25%.[26] Moatshe et al[27] reported that sporting activities accounted for 44.2% of all MLKIs, with skiing/snowboarding contributing to 29.4% of all MLKIs in their series of 303 patients with bicruciate ligament injuries. Similarly, literature regarding the prevalence of ACL skiing injuries has found that two-thirds of these injuries do not occur in isolation.[15,28] The prevalence of concomitant ligament injuries, including the medial collateral ligament (MCL) and lateral collateral ligament (LCL), has been reported to be 50.5% and 22.5%, respectively.[15] Again, similar to elite-level alpine ski racers, one retrospective study found that 32% of ACL-injured patients suffered MLKIs[29]; therefore, displaying the concern of these injuries spans all performance levels. While the data regarding knee ligament injuries in snowboarding are less robust,[20,30–33] Wijdicks et al's[31] review on snowboard injuries found the knee to be the most injured location among elite snowboarders, with ligament injuries being the most prevalent.

Establishing a diagnosis

History and physical examination

While there is an abundance of data regarding the biomechanical injury mechanisms for ACL injuries sustained during skiing and snowboarding, there are less data specifically describing the mechanisms for MLKIs. It can be assumed that MLKIs, given their complexity and diversity, are likely highly variable in their precise mechanism, but instead, as previously alluded to, are more commonly grouped by the degree of energy the patients were subjected to during the injury events.[34] Further analysis should be completed to investigate the mechanisms of action for strictly MLKIs. Furthermore, utilizing the patient´s description of the events, as well as any physical evidence, such as a GoPro or other video source, can provide other pieces of data that can be extremely helpful. As an example, below are certain specific questions:

1. Did you eject out of your skis, or did they remain on?
2. Did you make contact with another object/person? If so, from what side, or where was the source of contact?
3. What was the approximate speed at which you were traveling?
4. Did you come to an abrupt stop, or did you roll/slide down the hill?

These questions can garner information such as the direction and character of force (ie, one or multidirectional/torsional), magnitude of energy of the event, and whether the knee was potentially subject to multiple different “events” (ie, in a roll/slide event).

The physical examination is another essential component in the initial evaluation of a patient with a suspected MLKI. It is important to assess the lower limbs systematically and, in the case of unilateral injury, to compare it to the uninjured side. In the case that the patient is ambulatory during the time of examination, it is necessary to make note of the patient's posturing as well as their gait and ability to bear weight. The initial inspection should look for any swelling, ecchymosis, muscle atrophy, varus and valgus malalignment, and skin changes to the affected knee. Range of motion (ROM) assessment can be of value, specifically asymmetric recurvatum, as this can be an indicator of an MLKI, specifically injury to the PLC.

Another essential part of the physical examination for suspected MLKI is a detailed assessment of the ligament structures of the knee. While this part of the examination is best done under general anesthesia before the operation, it is important to be thorough at the initial patient encounter and perform a detailed examination. This part of the examination may be difficult in the acute setting secondary to guarding by the patient, hematoma, and other possible injuries at presentation. Collateral instability should be assessed via a physical examination, and if the index of suspicion is raised or not conclusive upon examination, stress radiography for objective assessment should be performed. Missed coronal instability has been shown to be a risk factor for increased graft forces on the cruciate and also leads to an increased risk of ACL reconstruction failure, specifically in the setting of varus instability.[35,36] Therefore, we should have a high level of suspicion for MLKI in cases where an ACL injury has been diagnosed through physical examination. Additionally, patients who sustain high-energy trauma should be evaluated for potential MLKI and other concomitant organ injuries.

Furthermore, as with any high-trauma situation at the initial presentation, a detailed assessment of the limb's neurovascular status is vital. A bilateral examination of the pedal pulses should be performed, and it is essential to compare the injured limb with the contralateral limb in the case of unilateral injury. It should be noted that research has shown that roughly 23% to 32% of knee dislocations are associated with a compromise to the popliteal artery.[37] For a vascular injury in the setting of an MLKI, an ankle-brachial index (ABI) is a helpful tool and should be performed. It has been reported that an ABI of < 0.9 has a sensitivity of 87% and a specificity of 97% when diagnosing arterial disruption.[38] Thus, it is recommended that patients with an ABI < 0.9 undergo a further assessment with computed tomography (CT) angiography to best assess the vascular status of the limb.[39] Furthermore, in cases of morbidly obese patients, dislocated knees at presentation, or concomitant lateral side injuries and peroneal nerve injuries and/or fractures, CT angiography is recommended despite the initial presence of pulses because these are associated with a high risk of vascular injuries. Neurological injuries commonly occur concurrently with arterial injury, and sensory/motor function of the peroneal and tibial nerve should be assessed. Peroneal nerve injuries are the most common nerve injury after knee dislocation,[40] occurring in approximately 25% of cases; thus, the physician must perform a detailed examination of sensation to the anterolateral leg and dorsum of the foot.[41] The peroneal nerve runs along the posteromedial aspect of the biceps femoris tendon and courses around the neck of the fibula before entering the anterior compartment of the leg and is closely related to the posterolateral structures. PLC injuries, including avulsion of the biceps femoris tendon, have been demonstrated to be associated with an increased risk of peroneal nerve injuries.[27,42,43] Moatshe et al[27] also found that patients who had a PLC injury had 42 times greater odds of experiencing a peroneal nerve injury and 9.2 times greater odds of experiencing a popliteal artery injury than patients without a PLC injury. Additionally, patients with peroneal nerve injury had 20 times greater odds of experiencing concomitant vascular injury. Of note, 8% of peroneal nerve injuries result from sport-related knee fractures or dislocations, half being from skiing alone, making the physical examination a critical component of assessing ski and snowboard injuries.[44]

Examination under anesthesia

An examination under anesthesia (EUA) of the knee provides reliable diagnostic information about ligament structures.[45–47] An EUA is always performed in the operating room before proceeding with the further surgical intervention of MLKIs and allows for confirmation of physical examination findings and planning for operative treatment. It also provides time to obtain stress radiographs with intraoperative C-arm imaging, which is especially important in cases where preoperative stress radiographs are unobtainable.[48] As outlined by Floyd et al,[49] EUA entails a full-knee ROM, posterior and posterolateral drawer, Lachman's, pivot shift, and dial tests, both in extension and at 30° of flexion, as well as assessment of the proximal tibiofibular joint. All examinations are performed bilaterally to account for physiologic laxity and positive findings relative to the contralateral uninjured side.[34] Each assessment is repeated during the surgical intervention and validated with intraoperative findings.

Imaging studies

In the workup of a suspected MLKI, plain radiographs can aid in the diagnostic evaluation of these injuries. Both an anteroposterior and lateral view are recommended to screen for fractures and any indirect signs of ligament injury.[50] The literature has shown that fractures are known to occur in 10% to 20% of all knee dislocations.[51] Coronal and sagittal alignment films should be obtained as well in chronic cases and failed reconstructions because they are of vital importance regarding appropriate surgical management of these complex injuries. In the setting of significant coronal or sagittal malalignment, a corrective osteotomy may be indicated.[52]

Stress radiographs can provide an objective tool to measure the integrity of the MCL, LCL, and PCL in the setting of an acute and chronic knee injury. In a study performed by Kane et al,[53] varus stress radiographs demonstrated greater sensitivity in the diagnostic capabilities of FCL injury identification in the chronic setting compared with magnetic resonance imaging (MRI); overall sensitivities were 70% and 66%, respectively. However, it is important to note that in the case of an acute FCL tear, the MRI was proven to be more sensitive.[53,54] In a similar sense, the kneeling technique for the PCL stress radiograph has provided a reproducible method to quantify posterior knee instability.[34] Stress radiographs should be obtained as a part of the clinical workup when the concern for coronal or PCL instability is elevated. Further, these stress films may need to be repeated during the EUA due to patients' inability to tolerate them in the clinic, potentially leading to inaccurate measurements.[55] Lastly, these images should also be obtained at predefined postoperative time points to assess maintained stability.

MRI remains an important advanced imaging tool for the diagnosis of MLKI; however, its efficacy remains a debated topic. Helito et al[50] reported that in acute settings, MRI could be difficult to interpret due to edema and hemorrhage in the surrounding ligamentous structures, therefore recommending the subacute-phase MRI. Similarly, Sanchez-Munoz et al[56] reported varying diagnostic accuracy between knee structures, with risks of misdiagnosis, particularly with PLC, meniscal, and chondral lesions. This is especially relevant given the recent literature; for example, Moran et al[57] reported that 37.5% of MLKI patients with an intact ACL had medial meniscus ramp lesions on MRI, signifying the importance of also considering meniscal pathology on presentation.[57] Similarly, in a multicenter study on MLKI, Poploski et al[58] reported that 55.6% of the patients had meniscal injuries and 5% had meniscal root tears. Although these risks are present, the MRI remains more specific and sensitive than the CT scan in assessing for knee ligament injury.[59] Previous literature has shown near 100% sensitivity in acute MLKI,[53,60] whereas more recent data have reported the sensitivity of the ACL and PCL to be 90.7% and 90.4%, respectively.[61] For the ACL, immediately after rupture, increased signal intensity within the ligament is seen, and lateral femoral condyle and posterior tibial plateau bone contusions are common. Contrastingly, PCL rupture has a lower signal intensity and is identified instead by thickening of the ligament; an anteroposterior diameter of 7 mm or greater was said to indicate a high sensitivity and specificity of a tear.[59,62] Complete assessment of known PCL tears is especially important, and the utilization of MRI should be warranted, given their association with MLKI. This includes analysis of the PLC and PMC, which, if overlooked, can cause significant morbidity and may compromise the outcome of cruciate ligament reconstructions.[59] According to Geeslin and LaPrade,[63] anteromedial femoral condyle bone contusions, visible on MRI, are seen in 80% of PLC injuries and should be considered evidence of a PLC injury until proven otherwise. Additionally, the same bone bruising pattern is a highly sensitive finding correlated with common peroneal nerve injury on physical examination.[64] This is an important consideration when analyzing MRI data, given the high neurovascular injury risks associated with MLKIs. Medially, the superficial and deep MCL and the posterior oblique ligament (POL) are best seen on coronal and axial MRI scans, with grade I medial injuries demonstrating preligamentous edema to grade III injuries showing complete disruption of the superficial and deep MCL.[59] Compromise of the POL may arise with injury to the semimembranosus and posterior horn of the medial meniscus, visible on imaging.

Treatment rationale

Nonoperative treatment

Operative versus nonoperative treatment for MLKI in the past was an area of contention within the field of sports medicine. Recent literature has delved into this topic to reach an evidence-based conclusion to obtain the best outcomes following the treatment of these complex injuries. Richter et al[65] performed a retrospective study looking at surgical repair or reconstruction of the cruciate ligaments versus nonsurgical treatment in those with traumatic knee dislocations. The results showed that the outcome scores were higher in surgical patients than in the nonsurgical patients. Additionally, they noted that those who had sports injuries rather than motor vehicle accident injuries, as well as those who had undergone functional rehabilitation rather than immobilization, had better outcome scores. Additionally, Peskun and Whelan[10] performed an evidence-based review of operative versus nonoperative treatment of MLKI. Their study consisted of a total of 855 patients from 31 studies who were managed operatively and 61 patients from 4 studies who were managed nonoperatively. The results of the review provided further evidence for the superiority of operative management in these types of injuries. Furthermore, it is important to note a meta-analysis performed by Dedmond et al,[66] which further evaluated operative versus nonoperative treatment. In this study, a total of 132 knee dislocations were treated surgically, while 74 were treated nonoperatively. The average ROM was 132° in the surgical group compared to 108° in the nonsurgical group; these results were significant. Additionally, the study demonstrated that Lysholm scores were higher among the surgical group, 85.2 versus 66.5. Levy et al[3] conducted a systematic review whose results supported the findings by Dedmond et al. Their results showed that in the 4 studies that compared surgical treatment with nonoperative treatment, there was a higher percentage of excellent/good International Knee Documentation Committee (IKDC) scores (58% versus 20%) in surgically treated patients, as well as higher rates of return to work (72% versus 52%) and return to full sport (29% versus 10%). The results of the studies by Dedmond et al. and Levy et al presented above are not perfect, nor are they randomized trials, where the decision to proceed nonoperatively in certain patients was likely due to comorbidities, but they do demonstrate improved outcomes; thus, operative management has become the standard of care to promote the most optimal outcomes for return to sport and functionality. In regard to the ability to return to skiing and snowboarding, due to the more extreme amounts of knee flexion and force transmitted through the tibiofemoral joint, a lack of knee motion and instability are likely to be dysfunctional and poorly tolerated.

Repair versus reconstruct

An understanding of the surgically relevant biomechanics for the major ligaments of the knee is essential for a successful outcome in multiligament repair and reconstruction. Braaten et al[67] outlined a biomechanical summary of the relevant knee structures involved in multiligament injuries and agreed that it is also important to consider the relationship between biomechanical function, mechanism of injury, and the injured structures involved, because this may dictate patient-specific treatment, such as in skiing/snowboarding high-energy trauma. That said, the nature of a skiing/snowboarding injury in these cases may dictate the discussion regarding repair and reconstruction.

There has been much debate regarding the surgical treatment of MLKI injuries; for surgical repair versus reconstruction, previous literature has established that reconstruction provides superior outcomes in reproducing the native anatomy and stability of the knee.[68] For the ACL, it has long been established that primary repair results in poorer outcomes than ligament reconstruction.[52,69,70] Treatment of the PCL, however, has been less certain due to its greater healing potential after injury, but its high rate of concomitant injury needs particular consideration in surgical management.[34,71] In MLKIs specifically, Mariani et al[70] found that patients following knee dislocation who underwent cruciate ligament repair experienced higher rates of flexion deficit, posterior tibial instability, and decreased rates of returning to preinjury performance. This is especially important when considering high-level skiing and snowboarding athletes seeking to return to professional sports. A debate has also continued regarding single- versus double-bundle reconstruction of the PCL. The 2-part studies by Kennedy et al[72] and Wijdicks et al[20] determined that both the anterolateral bundle and posteromedial bundle are codominant, stating that double-bundle reconstruction most effectively mimics native PCL stability compared to single-bundle. The following year, Kennedy et al reported double-bundle PCL reconstruction as being better to restore the native biomechanics and kinematics of the knee.[73,74] While a recent meta-analysis by Migliorini et al[75] on single- versus double-bundle reconstruction concluded that current evidence does not support the double-bundle technique, most studies included in Migliorini et al demonstrated superior outcome scores and decreased laxity in patients undergoing double-bundle PCL reconstruction. Additionally, a flat tibial slope has been reported to increase forces on the PCL; therefore, it is the authors' view that a double-bundle PCL reconstruction should be considered for patients with a flat slope in order to have a large-enough graft to withstand the forces and reduce the risk of the graft stretching out and reconstruction failure.

For the PLC, surgical management has been important in approximating native knee stability and function. Between repair and reconstruction, Stannard et al[76] reported PLC injury reconstruction failure rates of 9% compared to 37% in patients who underwent repair. Similarly, Levy et al[77] reported a 6% failure rate in reconstruction patients versus 40% in repairs. Additionally, Geeslin and LaPrade[68] found the surgical treatment of grade III PLC injuries with the repair of avulsed main PLC structures along with reconstruction of midsubstance tears of the PLC to best approximate the native knee stability. In concomitant PCL ruptures and PLC injuries, several studies have also reported that greater knee function and stability are achieved from reconstruction, as outlined by LaPrade et al.[34] Contrastingly, repair of avulsion injuries of the PLC has demonstrated to yield satisfactory functional outcomes with low failure rates (10%).[78] Thus, repair of the PLC should be reserved for avulsion injuries, and augmentation can be considered based on tissue quality in order to allow for early rehabilitation.

Medial compartment injuries are also particularly important, given that they are the most common injury in MLKI patterns.[27,52] For example, Moatshe et al evaluated 303 patients with MLKI, 52% of which included the medial compartment.[27] Isolated MCL injuries can often be treated conservatively with proper rehabilitation;[79] however, MCL injury in the context of MLKI is commonly repaired/reconstructed if found unstable during EUA.[80] LaPrade et al reported that in MLKIs with medical compartment injury, primary repair of medial structures is reasonable, but in severe midsubstance injuries or chronic medial knee injuries, reconstruction is recommended.[79] In the common injury pattern of concomitant ACL and MCL injury, nonoperative management of the MCL has been successful with proper rehabilitation while the ACL is reconstructed.[81–84] Previously, Halinen et al[82] reported that with acute combined ACL and grade III MCL tears, MCL surgery was unnecessary. More recently, Westermann et al's[81] multicenter study reported no subset of patients with severe combined ACL and medial knee injuries as having benefited from operative treatment of the medial compartment. Additionally, Noyes and Barber-Westin[83] previously cited worse outcomes with ACL reconstruction and MCL repair versus ACL reconstruction and nonoperative management of the medial compartment.

Timing of surgery and staged versus unstaged procedures

The timing of surgery in MLKIs has been debated in the literature and, in many cases, may come down to clinical judgment. There are several contributing factors to the timing of surgical management, including concomitant fracture, extensor mechanism injury, neurovascular injuries, open versus closed knee dislocation, degree of knee instability, unacceptable soft tissues, envelope injuries, other life-threatening injuries, and overall patient health at the time of injury.[3,85] Mook et al's[86] systematic review previously assessed operative intervention timing in MLKIs, further displaying the risks and benefits of surgical timing. Regarding ligament stability, they found that acute treatment resulted in significantly greater anterior instability compared to chronic; however, there were no statistical differences posteriorly or with varus/valgus laxity. Additionally, severe flexion deficits and manipulation under anesthesia, or second operations for knee stiffness, were more likely for acutely treated patients compared to chronic. In contrast, patients treated chronically had significantly lower excellent/good outcome scores than those of acute or staged patients at 2-year follow-up, assessed by multiple rating scales.[86] Staged procedures produced the highest percentage of excellent/good subjective outcomes but entailed higher rates of joint stiffness than chronic treatment. Additionally, in 2017, Moatshe et al's[52] prospective review reported on 303 patients with a knee dislocation (KD), finding the patients treated acutely compared to chronically developed arthrofibrosis at 15.2% and 3.8%, respectively, displaying similar trends in joint stiffness to Mook et al.

Although there have been risks reported of joint stiffness with acute treatment, much of the conversation has begun to favor acute surgical management with reconstruction.[3,34,80,87,88] Levy et al's[3] evidence-based systematic review previously assessed 5 studies comparing early and late surgery in MLKIs. Early surgery was identified as ≤ 3 weeks from injury and was found to have higher mean Lysholm scores, 90 versus 82, and a higher percentage of excellent/good IKDC scores, 47% versus 31%, in comparison to late surgical treatment. Additionally, they found that patients receiving early surgical management had statistically higher sports activity scores on the Knee Outcome Survey compared to those receiving late treatment, 86 to 69, respectively. That said, there was no significant difference in activities-of-daily living scores or mean ROM or flexion loss.[3] Additionally, while Marder et al's[89] systematic review reported insufficient evidence to determine superior clinical or functional outcomes from either early or late surgical intervention, Ng et al[80] stated that acute or staged reconstructions provide better outcomes in MLKI. Similarly, a meta-analysis by Hohmann et al[87] and a systematic review by Sheth et al[90] both reported better clinical and functional outcomes with early surgical intervention in MLKI. Lastly, LaPrade et al[34] reported 2 years ago that the existing evidence favors the rationale for early, single-stage operative management of MLKIs. These studies further emphasize the debate of acute versus chronic treatment, given there are several factors at play when considering successful patient outcomes.

There is debate about the benefits of staged procedures as well. Several studies have reported satisfactory restoration of knee function, stability, and ROM with a staged technique.[86,91,92] For example, Ohkoshi et al[92] reported good clinical outcomes following 2-stage reconstruction in MLKI, reconstructing the PCL acutely within 2 weeks of injury, followed by reconstruction of the ACL and PLC 3 months following. Subbiah et al[91] also referenced the benefit of delaying ACL reconstruction for further evaluation, mentioning that the ligament's reconstruction is not necessary for all patients who are doing well without it. In contrast, several studies have reported that staging the reconstruction can potentially alter joint kinematics and increase the risk of graft failure or other complications.[35,36,93] It is important to note that Braaten et al[67] also mentioned the concern of staged surgery stretching out reconstructed grafts given the interconnected and codependent nature of the integrity of other knee structures. The contested nature of staged versus unstaged procedures warrants further assessment in the literature regarding MLKI outcomes.

Graft selection

Many factors are at play when considering graft selection in MLKIs. For skiing and snowboarding athletes, this is especially important for optimal return to sport. For the ACL, a bone–patellar tendon–bone (BTB) autograft has been the gold standard for active, skeletally mature individuals. Chahla et al[94] previously recommended the single-bundle BTB autograft, while Braaten et al[67] recommended BTB autografts in MLKIs. Additionally, Persson et al[95] assessed 12,643 patients and reported a preference for BTB over hamstrings tendon (HT) autograft. In more recent years, the quadriceps tendon (QT) autograft has grown in popularity as well, making it a reasonable option for reconstruction. Dai et al's[96] systematic review and meta-analysis in 2022 reported that QT autografts had comparable outcomes and graft survival to those of both BTB and HT autografts. Additionally, they stated that donor site morbidity was significantly lower with QT autografts compared to BTB and HT autografts.

For the PCL, double-bundle reconstruction is recommended, as described above. Regarding autograft versus allograft, Razi et al[97] recommended allograft reconstruction of the PCL, especially in the setting of an MLKI. Allograft options for the PCL include Achilles, tibialis anterior/posterior, and peroneus longus tendons.[98] LaPrade et al[34] recommended an 11-mm-wide Achilles tendon allograft for the anterolateral bundle and a tibialis anterior allograft for the posteromedial bundle. Autograft options for the PCL double-bundle technique include QT for the anterolateral bundle and HT for the posteromedial bundle.[34,98]

For the PLC, including the LCL, PLT, and PFL, split Achilles tendon allograft has been a successful reconstruction technique by LaPrade et al that has been cited in the literature.[52,67,99] Concerning autograft techniques, HT autografts have been used[100] in addition to semitendinosus and gracilis autografts.[101] The higher costs and limited availability of allografts in some countries have been cited as justification for the benefits of PLC autograft reconstruction.[52,67,99,101]

As discussed above, the medial compartment of the knee responds well to nonoperative measures in many cases. However, when reconstruction of the PMC is necessary, including the MCL and POL, graft options include semitendinosus tendon or peroneus split autografts and semitendinosus, peroneus longus, or tibialis posterior tendon allografts.[102]

Following surgical treatment

Outcomes

The ultimate end goal in the treatment of MLKIs following skiing and snowboarding accidents is to help the patient return to the preinjury sport level. For the past couple of decades, researchers have devoted their time to investigating the factors that lead to better outcomes in both subjective and objective measures. These include Multiligament Quality of Life scores, Tegner activity scores, Lysholm scores, Western Ontario and McMaster Universities Osteoarthritis Index scores, IKDC scores, patient-reported outcome measures, and many others.[8,66,67,103,104] The outcomes of these injuries can be influenced by a variety of factors, and it is important to be cognizant of them in the production of a management plan for these MLKI cases.

Studies have demonstrated that surgery and rehabilitation are important factors in regard to patient-reported outcomes and return to play. LaPrade and colleagues[104] reported a case series in which they followed 276 patients with MLKIs that occurred during sports participation. One hundred ninety-four of the patients had a follow-up at a mean of 3.5 years, and Tegner activity scores, Lysholm, and Western Ontario and McMaster Universities Osteoarthritis Index scores were recorded. They discovered that there were improved postoperative outcomes with lower complication rates in those who underwent single-stage anatomic reconstruction with immediate postoperative rehabilitation. Additionally, similar results were produced by Sheth et al in a systemic review of MLKIs in early versus delayed surgery.[88] Their study further supported the idea that earlier surgery (< 4 weeks) and early knee motion significantly improved Lysholm scores compared to those who delayed the procedure.[89] Similar results to the previous study described were concluded in further studies performed.[87]

Additionally, patient demographics could play a role in the outcomes of MLKI. In a study performed by Levy and colleagues, at an intermediate to long-term follow-up status post MLKI reconstruction, patients greater than the age of 30 had inferior IKDC (61.9 vs 73.3) and Lysholm scores (68.5 vs 76.9) compared to those less than 30.[105] However, it should be noted that many individuals over the age of 30 can do well from reconstruction as a treatment for MLKI.

When evaluating elite-level athletes, Borque et al[8] reported the favorable outcomes that can occur in this population. One hundred and twenty of the 136 athletes (88.2%) in the study population were able to return to an elite level of sport at an average of 12.8 months post operation. Furthermore, those with bicruciate injuries had a longer return to play time compared to those with MLKI involving a single cruciate ligament, but in the end, the rates were similar (83.3% vs 88.9%). In addition, Bakshi et al[7] demonstrated that National Football League athletes with ACL and MCL tears had significantly higher and quicker return-to-play times compared to those with ACL and PCL/LCL tears. Specific to skiing and snowboarding, but not to MLKIs, X-Games skiing and snowboarding athletes also have a high return to sport rates after ACL reconstruction, with 87% and 70% rates, respectively.[106]

It is the senior author's preference and opinion that the best outcomes are achieved with a single-stage anatomic reconstruction of the torn ligaments with early functional rehabilitation. For athletes and patients with access to rehabilitation, single-stage surgery will also allow for early and single rehabilitation periods and return to activities compared to staging, which will require 2 or more rehabilitation periods and a longer time to return to activities. However, the decision on whether to perform a single stage or staging is influenced by many factors, including concomitant injuries, the experience of the team, availability of resources, and surgeon preference. Studies comparing staging versus single stage have not found planned staging to yield inferior outcomes.[86] Staging might yield better outcomes in knee dislocations involving 3 ligaments (KD III).[107]

Rehabilitation and return to sport

Factors that play a role in the return to sport occur well before physical rehabilitation is underway. Deciding when to have surgery is an important factor to consider. Levy et al[77] demonstrated that athletes who have surgery within the first 3 weeks of MLKI have higher return to sport rates than those who undergo surgery in the chronic stage. Furthermore, Stannard et al[38] showed that in the management of PLC injuries, reconstruction cases had a higher return to sport rate compared to repair cases, 51% versus 23%. Later stages of rehabilitation have shown that the adjuvant use of orthopedic biologic therapy such as bone marrow aspirate concentrate and platelet-rich plasma, as well as blood flow restriction, may improve return to sport rates.[11]

As important as the surgical treatment is, clinicians must recognize that postoperative rehabilitation is an essential and critical process to promote the best functional outcomes after MLKI. This also includes psychological readiness for return to sport after a serious injury.[108] Evidence has shown that clinical outcomes and the return to competition after MLKI are heavily dependent on the postoperative rehab protocol and timing.[109] Richter et al[65] demonstrated that postoperative functional rehabilitation was the most significant prognostic factor overall and led to a return to sport rate of 63% compared to those who underwent postoperative immobilization, who only had a rate of 39%. As previously mentioned, DePhillipo et al[11] demonstrated a case of a 28-year-old Olympic-level female who sustained an MLKI, underwent surgical reconstruction, and returned to the sport at an Olympic level. It should be noted that this case involved a meticulous and well-thought-out plan to return the athlete back to the level at which they once competed. The study demonstrates a postoperative rehabilitation protocol that focuses on the restoration of motion while simultaneously protecting the reconstructed ligaments in the early stages of rehabilitation. In support, Keeling et al[9] produced a systematic review on postoperative rehabilitation following MLKI. Their findings support the idea that early physical therapy and ROM can lead to improved outcomes following MLKI, although they do note that there is a paucity of high-level evidence (randomized studies) about this topic. Monson et al[103] lay out a comprehensive plan and timeline for return to sport following MLKI. It follows a series of steps within the rehab plan, and they are as follows: phase 1 "recovery" (0-8 weeks), transition phase "acclimation to load" (8-10/12 weeks), the middle phase "rebuild" (10 weeks to 6 months), the late phase "restore" (6 months to 1 + year), and, lastly, the return to run and sprint. It is important to note that the authors stress the importance of measuring objective measures, such as strength, balance, and power, throughout the phases of the rehabilitation plan to track the progress. Unfortunately, there are no present studies that have not directly investigated the efficacy of their stated plan.

As with any rehabilitation process and goals for return to play, patients will encounter roadblocks that will limit their physical progression. Arthrofibrosis is one of them. Arthrofibrosis is seen to be one of the most common complications following MLKI treatment, with reported rates of up to 57%.[110] A systematic review performed by Fahlbusch et al[111] looked into 25 studies with a total of 709 patients who underwent treatment for MLKI. They discovered that in the selected studies, the diagnosis of arthrofibrosis (AF) was imprecise and subjective; a total of 86 patients were treated for AF and had a prevalence range of 2.8% to 57.1%. Some of the risk factors that were identified to cause AF included higher-grade injuries (Schenck III-IV), acute treatment, and ROM-limiting rehab protocols. While manipulation under anesthesia and arthroscopic lysis of lesions are potential treatments for AF, it is important to be proactive in its prevention. Considering these factors, the chances of AF occurring following reconstruction always need to be considered. These claims are further supported by another systematic review conducted by Sheth et al.[88] Their study further showed that AF can occur when reconstruction is done in the early stages. However, the subsequent subgroup analysis showed no difference between early and delayed surgery when only studies employing an early ROM protocol were pooled.[88] Thus, it is important to further promote early ROM to prevent AF and the hindrance of rehabilitation, but, at the same time, be aware that aggressive ROM started too early may increase the risk of stretching or damaging the healing tissues.

Prevention of MLKI in skiing and snowboarding

Preventative measures can go a long way in the reduction of knee injuries in skiing and snowboarding. In the current literature, there are many studies investigating various interventions to reduce the incidence of ACL tears on the slopes. Downhill alpine skiing is a physically demanding sport that requires well-developed neuromuscular control, muscular strength, and aerobic endurance. Wang et al[112] demonstrated in a prospective cohort study that recreational alpine skiers with inferior lower-extremity agility, through a hexagonal obstacle test and balance through the Y-balance test, have a higher injury risk. Additionally, studies have demonstrated that weaker core flexion strength and poorer neuromuscular control can lead to a higher risk for ACL rupture while skiing.[113] Westin et al[114] showed that ACL injury prevention programs in competitive high-school skiers can reduce the incidence of injury. The targeted education program focused on both indoor and outdoor exercises on snow with an emphasis on core stability, as well as neuromuscular control. Additionally, the program focused on the isolation of the individual lower limbs, as alpine skiing is an equilateral sport. Their results showed a 3.9% incidence rate of ACL tear in the experimental group ($n = 305$) compared to the control (8.1%, $n = 431$).

Furthermore, skier education has been shown to play a critical role in the prevention of serious ligamental injuries in the knee. Ettlinger et al[115] demonstrated a targeted education program that involved the viewing of videotaped scenes of where knee injuries occurred given to ski patrollers and instructors. The video program was focused on improving psychomotor abilities to develop a keen awareness of the events that lead to ACL injury. The results of the study demonstrated that such a program could reduce the rate of serious knee sprains by 62%. In addition, as described previously in this review, researchers were able to determine 3 main mechanisms by which ACL injuries in world cup alpine skiers occur.[116] Further research should be conducted to identify the strategies for preventing these common injuries, thereby enhancing skier education.

It is important to note that the exciting innovation within the ski equipment industry over the past couple of decades has come at a cost. The equipment used over time continues to play a role in knee ligament injuries in skiing and snowboarding. Although shorter carving skis are more commonly used than in previous decades, their use still correlates with ACL rupture being the most frequent knee injury diagnosis, with an incidence ranging between 15.8% and 16.7%.[117,118] Additionally, ski boot sole abrasions increase the risk of ligamentous injury for male and female recreational skiers.[119] Promising enough, Ruedl et al[120] demonstrated that reducing the ski length, narrowing the ski tip width, lowering the rear standing height, and a lower standing height ratio can lead to a reduced likelihood of ACL injury. These previous factors should be considered when renting, purchasing, or even developing skis to reduce ACL tears. Although all of these studies are conducted and focused on ACL tear prevention, it is important to recognize that they may be applicable in the prevention of MLKI. While MLKI in skiing is far less common than ACL injuries, further research is needed to investigate the prevention of MLKI alone.

Author preference for treating ski and snowboard athletes

The authors' preference for treating the injuries in ski and snowboard athletes is early single-stage surgery in order to allow for early protected functional rehabilitation. Our preferred graft choices are BTB or QT for the ACL. Anterior knee pain can be an issue in alpine racers; therefore, QT should be considered in these patients. For PCL reconstruction, a double-bundle PCL reconstruction where available or contralateral quadriceps (if ipsilateral graft is used for ACL reconstruction) provides a large enough graft to withstand the forces they are subjected to in the sport. MCL repair and augmentation with semitendinosus autograft and allograft or contralateral hamstrings can be used for the PLC reconstruction. Early single-stage surgery will increase the likelihood of an early return to activities and sports. The athletes should be partial weight bearing for the first 6 weeks in order to reduce the load on the knee and the risk of swelling, which can inhibit motion and cause pain. Return to sports can be expected at 9 to 12 months and longer in those with PCL or PLC involvement. Using an activity brace during the first season after the injury can be beneficial and should be discussed with the athletes returning to skiing or snowboarding.

Conclusion

MLKIs are significant and devastating injuries that occur in the winter sports of skiing and snowboarding. While MLKIs are rare injuries overall, knee ligament injuries are the most common injury types among skiers, and MLKIs are most common in skiing compared to other extreme sports.[25] While there are much data on ligament injuries occurring in alpine skiing, additional data are necessary to fully understand the prevalence of MLKIs in skiing and snowboarding. For treatment, there is a consensus that operative is superior to nonoperative management, but more data are needed on the timing, surgical technique, and rehabilitation for optimal outcomes. Improved functional outcomes and return to sports can be expected after surgical treatment of MLKI in skiing and snowboarding; however, long rehabilitation, especially for bicruciate injuries, is common. Future studies should consider a more targeted analysis of MLKIs in skiers and snowboarders specifically.[121]

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Ethics approval

This is a state-of-the-art review article that does not contain any specific or identifying patient information and does not require patient consent.

Authorship contributions

This article has been edited, proofread, and approved by all authors involved. Each author believes that the article represents honest work.

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The authors declare the following financial interests/personal relationships that may be considered as potential competing interests: Robert F. LaPrade reports a relationship with Smith and Nephew Inc that includes consulting or advisory. Robert F. LaPrade reports a relationship with Ossur that includes consulting or advisory. Robert F. LaPrade reports a relationship with Arthrex Inc that includes consulting or advisory. Robert F. LaPrade reports a relationship with Elsevier that includes consulting or advisory. Robert F. LaPrade reports a relationship with American Orthopaedic Society for Sports Medicine that includes funding grants. Robert F. LaPrade reports a relationship with Arthroscopy Association of North America that includes funding grants. Robert F. LaPrade reports a relationship with Ossur that includes funding grants. Robert F. LaPrade reports a relationship with Smith and Nephew Inc that includes funding grants. Robert F. LaPrade reports a relationship with The American Journal of Sports Medicine that includes board membership. Robert F. LaPrade reports a relationship with Journal of Experimental Orthopaedics that includes board membership. Robert F. LaPrade reports a relationship with Knee Surgery, Sports Traumatology, Arthroscopy that includes board membership. Robert F. LaPrade reports a relationship with Journal of Knee Surgery that includes board membership. Gilbert Moatshe reports a relationship with Smith and Nephew Inc that includes consulting or advisory. Gilbert Moatshe reports a relationship with Journal of Bone and Joint Surgery Inc that includes board membership. Gilbert Moatshe reports a relationship with Journal of Arthroscopy that includes board membership. Gilbert Moatshe reports a relationship with International Society of Arthroscopy Knee Surgery and Orthopaedic Sports Medicine that includes board membership.

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