ABSTRACT

Examination and evaluation of the patient with multiple ligament injured knee is a complicated process and best done in a methodical, comprehensive fashion with a particular emphasis placed on assessment of supporting soft tissues. Tissues that can be damaged during this devastating injury include bones, ligaments, meniscus, articular cartilage, and neurovascular structures. Uses of diagnostic imaging and the physical examination process will be described in this article.

Key words: knee dislocation; physical examination; diagnostic imaging
INTRODUCTION
Patients with multiple ligament knee injuries (MLKI) always have the risk of severe disability due to the resultant loss of stability from damage to passive and active knee stabilizers. Additionally concerning is the possible compromise of neurovascular structures surrounding the knee. Although rare, the average sports and orthopedic clinician will undoubtedly have a patient with an injury of this magnitude in their career. This injury may be due, in part, to improved physical examination testing, diagnostic technology, and enhanced awareness of these complex injuries. Therefore, it is paramount that clinical examination of this potentially disabling condition be performed in a thorough and expedient manner for optimal functional outcomes to occur following this injury. Failure to properly diagnose, evaluate, and treat this injury can lead to a whole host of complications, some of which require amputation. Although many times clinicians rely on various forms of advanced technology via imaging, the foundation of evaluation of this, or any musculoskeletal condition, is performance of an efficient hands-on clinical physical examination.

HISTORY
The most common mechanism of injury causing knee dislocation is that of high-velocity motor vehicle or motorcycle accidents. Knee dislocations have occurred from low-velocity trauma in athletics also. Another common mechanism of injury is represented by trampoline accidents and spontaneous dislocations in the morbidly obese.

OBSERVATION/INSPECTION
Due to the deformity, pain, and swelling, the dislocated knee is not hard to diagnose while not reduced. Although the severely deformed knee dislocation is usually obvious to the naked eye, spontaneous reduction of dislocations and subluxations have been reported between 20-50% of the time. In these knees that spontaneously reduce, it is hard to believe that absence of a deformity would allow such a high level injury. In these cases the extent of injury may be easily mis-diagnosed. Additionally, in the obese patient the deformity and swelling may be obscured by excess adipose tissue surrounding the knee. Because of the potential for disastrous complications, the evaluation and treatment of the knee that has acute, multiple ligament injuries should be considered a knee dislocation, until proven otherwise.

Swelling can be helpful in defining the zone of injury of the knee. The knee may appear to have extensive soft tissue swelling proximally or surrounding the actual tibiofemoral joint. Swelling can be both intra-articular and extra-articular. Due to extravasations (leakage) of joint fluid into peri-articular soft tissues around the knee, intra-articular swelling may only be moderate if the synovial capsule is breeched. If the joint capsule is not ruptured, a significant joint effusion will most likely be present intracapsularly.

The patient should be examined for “dimple sign.” This finding is one of the hallmark signs of a posterolateral dislocation and occurs as a result of the infolding of the medial collateral ligament and capsule into the joint as the medial femoral condyle is forced posterolaterally.

Discoloration is not always noted acutely, but generally within several days following insult can give the clinician an idea of the extent of soft tissue injury. Similarly, boginess and extra-articular edema may suggest areas where capsular or collateral complexes have been disrupted.

NEUROVASCULAR EXAMINATION
First and foremost during the clinical examination is the immediate assessment of the neurovascular status of the dislocated knee. Due to the high incidence of vascular insult, all knee dislocations should assume vascular compromise until proven otherwise. Early diagnosis and appropriate immediate treatment of vascular injury is required to save the extremity. Collateral circulation may initially be sufficient enough to provide a normal pulse, giving the examiner a false sense of security. Despite this fact, lower extremity pulses should be assessed. Distal pulses are normally assessed by manual palpation and compared to the contralateral, normal leg. The presence or absence of the dorsalis pedis and the posterior tibial arteries should always be documented. The absence of pulses is a true medical vascular emergency. If not assessed early, the posterior tibial artery is often-times very hard to assess due to the significant amount of soft tissue swelling seen in and around the knee following dislocations. It must be recognized that a strong palpable pulse does not rule out an arterial injury. Both a palpable pulse and a warm foot can exist in the face of popliteal artery injury. The danger in this injury is an intimal flap tear of the artery which can cause a delayed occlusion up to 24 to 72 hours after the injury.
The popliteal artery always warrants assessment due to the high incidence of injury in the dislocated knee. The popliteal artery is transected with a posterior tibial dislocation, while it is stretched during the anterior tibial dislocation.\textsuperscript{20,21} Capillary refill alone is not accurate in evaluating the integrity of the popliteal artery.\textsuperscript{1} Tenseness in the popliteal region and the inability to “move the fossa” (defined as an inability to pinch the skin over the popliteal fossa because the fossa is so tight and filled with blood) are grave signs of vascular insufficiency.\textsuperscript{1}

Peroneal nerve palsy is also common following MLKI. The peroneal nerve is even more important to assess in the posterior knee dislocation due to disruption of multiple posterolateral structures. Examination of peroneal nerve function can be assessed by determining the sensory function of the dorsum and lateral aspects of the foot and first web space on the affected extremity. This examination can be assessed by light touch and sharp/dull discrimination. Motor function is assessed by active contraction of foot and toe dorsiflexion. Loss of peroneal nerve function will result in loss of sensation, foot drop, and an altered gait pattern.

**DIAGNOSTIC TESTING-RADIOGRAPHS**

Radiographic examination is paramount to begin the assessment of the dislocated knee. Anterior, posterior, and lateral views are used to assess the direction of dislocation, integrity of the bones, and to look for other clues about the injury. Avulsion fractures from attachments of cruciate and collateral ligaments are sometimes visualized.

**MAGNETIC RESONANCE IMAGING**

Magnetic resonance imaging (MRI) is almost an essential tool to assist in the diagnosis of the MLKI and assists in the formulation of the treatment plan.\textsuperscript{22} The MRI helps to evaluate meniscal tears, intraosseous contusions, occult fractures, capsular tears, and muscle strains. The MRI additionally helps with the preoperative planning for specific ligament reconstructions or repairs and determining the amount of graft that is needed for reconstruction.

**ARTERIOGRAPHY**

The selective use of arteriography based on physical examination is a safe and prudent policy following knee dislocation rather than routine arteriography in all instances. Stannard et al\textsuperscript{23} developed an algorithm for indication of ordering arteriography. The algorithm was successfully used to diagnose all clinically important vascular injuries in a large series of patients. The first step in this algorithm is to perform a physical examination of the dorsalis pedis and posterior tibial arteries, as well as a gross evaluation of color and temperature. If any asymmetry between the two lower extremities is present, the patient should have an arteriogram made either in the angiography suite or on the operating-room table. If any history of an abnormal vascular examination in the pre-hospital setting exists, the patient should also undergo arteriography. In the absence of these findings, the patient should be admitted for careful observation. Neurovascular checks should be performed by the nursing staff every 2 to 4 hours for the first 48 hours. The vascular examination should be documented by a surgeon at the time of admission, 4 to 6 hours after admission, and again 24 and 48 hours after admission. If any clinical abnormalities are detected, an arteriogram should be made.\textsuperscript{20}

**DIAGNOSTIC ARTHROSCOPY**

Diagnostic arthroscopy allows for further evaluation of the knee. This examination technique allows direct visualization of intra-articular anatomy and allows for clues as to what is damaged that is extra-articular. Capsular tears can be seen, as well as intra-articular capsular hemorrhaging. Articular surfaces, as well as the meniscus, can be evaluated for injury and a treatment plan can be instituted.

Caution must be employed with arthroscopy after a knee dislocation. If fluid extravasation through a ruptured capsule occurs, and if a pump is employed as part of the arthroscopy, a potential compartment syndrome could be created. A delay of 10-14 days from the injury can allow the capsule tear to seal and reduce the risk of a compartment syndrome. The use of a low pressure system including gravity and an outflow portal can reduce the potential risk of this serious complication.

**INITIAL TREATMENT AND REDUCTION**

The patient with the dislocated knee rarely presents with the knee dislocated. If the patient presents with a dislocated knee, evaluation should be performed with radiographs to evaluate for concomitant fractures. Once the patient has been evaluated with radiographs a reduction maneuver can be performed. Post-reduction radiographs are important to evaluate for a concentric reduction. These radiographs should be carefully studied for osteochondral fractures, as well. In addition, avulsion fractures can give clues to the soft tissue restraints that have been injured and help guide surgical technique in repair. If the knee is not reducible, then consideration should be given to soft tissue entrapment of the femoral condyle making the knee irreducible. Following reduc-
tion, the knee should be re-examined for neurovascular pathology.

CLASSIFICATION
Knee dislocations can be classified, according to the anatomic system proposed by Wascher. A KD-I is a dislocation associated with multiple-ligament injuries that did not include both cruciate ligaments, KD-II is a dislocation associated with a bi-cruciate ligament injury only, KD-III is a dislocation associated with a bi-cruciate ligament injury and a tear of either the posteromedial or posterolateral knee ligaments, KD-IV is a dislocation associated with tears of both cruciate ligaments and both posteromedial and posterolateral ligaments, or KD-V which is a dislocation associated with a periarticular fracture and multiple-ligament injuries.

LIGAMENT EXAMINATION
Following reduction, the ligament examination should be performed very carefully to avoid redislocation or further compromise to neurovascular structures. As with most examination procedures, stability examination should begin with an evaluation of the contralateral, non-involved extremity. This examination allows the athlete to understand what will happen to the involved knee and, hopefully, decrease any anxiety associated with clinical examination procedures. It is easy to get a false first impression and note abnormal translational movement on an individual who demonstrates a significant amount of generalized ligamentous laxity, which may not actually be pathologic.

Anterior Cruciate Ligament
The “gold standard” test for anterior instability is the Lachman’s test, which is performed at 30 degrees of knee flexion (Figure 1). Because the Lachman’s test is for single plane anterior instability, it is imperative in the athlete with MLKI to control rotary motions while performing this test. Allowing excessive internal or external tibial rotation while performing the Lachman’s test may result in false-positive results. Also remember that false-positives can occur in the athlete with a posterior cruciate tear because of the posterior tibial drop-back that occurs with that particular injury. In the face of combined ligamentous injuries the clinician may be misled by a knee that has an intact anterior cruciate ligament (ACL) but ruptured posterior cruciate ligament (PCL), medial collateral ligament (MCL), and lateral collateral ligament (LCL). To avoid this misinterpretation, place the knee in the anatomic position prior to performing the examination techniques. Flexing the knee to 90 degrees and positioning the tibia so that an approximate 10-mm step-off between the femoral condyles and the edge of the tibial plateau exist. Another method to find the neutral position is to palpate the step-off of the femoral condyles to the tibial plateau in the uninvolved knee and compare to the involved knee in a similar position. Both the end-point (mushy or absent) and the length of excursion determine a positive test.

The anterior drawer test can then be used to verify anterior single plane instability. This test may have decreased sensitivity and specificity in those with meniscal tears, acutely swollen knees, and protective hamstring muscle spasm. An advantage of this test is that the technique can be performed in a position of tibial internal and external rotation to assess for rotary instability of the posterolateral corner and posteromedial capsule, respectively. Grading of ligament laxity is always compared to the uninjured side. Grade I is defined as 0-5 mm, grade II from 6-10 mm, while a grade III is more than 10 mm of motion compared to that of the uninvolved side.

Posterior Cruciate Ligament
The PCL is examined via the posterior drawer test. This test is performed from a position of 45 degrees of hip flexion and 80 degrees of knee flexion with the feet flat on the examining table. The neutral position of the tibia must be found as described previously, before the test is performed to decrease the risk of obtaining false positive results. The clinician’s thumbs palpate the anterior joint between the femoral condyles and the tibial plateau. The fingers wrap around the tibia to palpate the hamstring muscles to assess for spasm. A posterior directed force is placed upon the tibia while feeling for both the quality and quantity of the end feel. Excessive posterior tibial translation, a soft end feel, or combination of the two is indicative of a PCL tear.
In this same position, the step-up test can be performed. In position above to start the posterior drawer test, the anterior portion of the tibial plateau is located approximately 10 mm anterior to the distal femoral condyles. Absence of this step-up is indicative of PCL injury (Figure 2). Lastly, the posterior sag test can be performed in which in the same position previously described, the patient is asked to completely relax and the affected knee is viewed from the side. A positive test occurs when the anterior aspect of the proximal tibia is found to “sag” behind the anterior aspect of the femoral condyles or in comparison to the contralateral knee.

Collateral Ligaments
The valgus stress test is applied to the knee in both extension and at 30 degrees of flexion (Figure 3). When the MCL is disrupted in the unanesthetized patient, pain may decrease accuracy of this test due to guarding. This test is done with the hip in only slight flexion and full knee extension with or without recurvatum equal to that of the uninvolved limb. A significant amount of valgus motion in full extension is indicative of an ACL or PCL rupture, the posterior oblique ligament, and the medial portion of the posterior capsule. The ACL is a secondary restraint to medial joint opening.

The test is then performed again in 30 degrees of knee flexion to place laxity on the posterior capsular structures. Medial laxity in only 30 degrees of flexion that is not present in full extension indicates injury to only the MCL.

The varus stress test is performed in a similar manner as the valgus stress test (Figure 4). The knee is tested at both full extension and 30 degrees of knee flexion. Lateral instability in full extension indicates rupture of LCL, lateral capsule, and PCL. Laxity at 30 degrees only indicates an isolated tear to the LCL.

Posterolateral Corner
To examine for capsular sprain of the posterolateral corner of the capsule, the external rotation recurvatum test (ERRT) is performed. During the ERRT, the examiner grasps the great toe of each foot while the supine athlete’s knees are allowed to fall toward full passive extension (Figure 5). This test is considered positive when the affected knee assumes a posture of varus angulation, hyperextension, and external rotation of the tibia as compared to the uninjured extremity. This test must be done very carefully in the patient with MLIK since disruption of the posterior capsule may allow excessive genu recurvatum, allowing the knee to redislocate.

The dial test assesses abnormal external tibial rotation to differentiate between isolated posterolateral corner injury and combined ACL/PCL injuries. This test is most commonly performed in the prone position with the knees flexed to 30 degrees (Figure 6). An external rotation force is applied to the athlete’s heels by placing the fingers and thumb along side the talor-calcaneal bony contours. The foot-thigh angle is measured and compared to the uninjured knee. The test is then performed in 90 degrees of flexion and the foot-thigh angle is re-measured (Figure 7). When comparing at either angle a difference of 10 degrees or more is significant. As the knee is flexed to 90 degrees a reduction in increased rotation may occur although the amount of motion remains greater than the uninjured side if the PCL is still intact. This
increased rotation occurs because the PCL is the secondary stabilizer to external rotation and gains mechanical advantage when the knee is flexed.\textsuperscript{15} When the amount of external rotation is increased from 30 to 90 degrees, a combined PCL and posterolateral corner of the capsule injury is incurred.\textsuperscript{31,32}

Although not usually tolerated well in the athlete who is awake, the pivot shift test is best described as a reduction from a state of anterior tibial subluxation.\textsuperscript{33} The athlete will assume a supine position with the leg relaxed as much as possible. The examiner should hold the affected knee in full extension and internal rotation with the hip flexed about 45 degrees. The knee is flexed while the examiner applies a valgus stress. In an athlete with a deficient ACL, the lateral tibial plateau will be anteriorly subluxated at the beginning of the test. As the amount of flexion increases to 30-40 degrees, this anterior position of the tibia will be abruptly reduced. This reduction can be both palpable and audible.\textsuperscript{34}

**SUMMARY**

The acute examination and assessment of patients with the MLKI is crucial for multiple reasons including accurate knowledge of injury pattern and surgical or conservative treatment and decision making. The evaluation technique should be consistent, methodical, and comprehensive. As an adjunct to the physical examination, diagnostic imaging should be used when appropriate.

**REFERENCES**


INVITED CLINICAL COMMENTARY
MULTILIGAMENTOUS KNEE INJURIES – SURGICAL TREATMENT ALGORITHM

Charles L. Cox, MD
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ABSTRACT

The concept of multiligamentous knee injuries encompasses a large variety of presenting combinations, and the existing published literature lacks adequately sized prospective comparative patient-reported outcome studies to guide clinical decision making. The decisions of operative versus nonoperative management, timing of surgery, repair versus reconstruction, use of allograft versus autograft, choice of which ligaments to treat, and rehabilitation protocols remain controversial despite the fact that multiligament injuries have been shown to represent approximately 11-20% of knee ligament sprains presenting for treatment. For the purposes of this manuscript, a multiligamentous knee injury is defined as one complete cruciate tear (grade III) plus a partial or complete collateral tear (grade II or III) or a partial or complete tear of the other cruciate (grade II or III). A surgical treatment algorithm is proposed based upon a review of case series literature and clinical experience in an academic sports medicine practice setting. Use of our proposed surgical algorithms may facilitate clinical decision making in an attempt to restore stability, preserve function, and maximize return to activity.

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INTRODUCTION
The concept of multiligament knee injuries comprises a wide range of ligament and intra-articular injury patterns. These complicated injuries necessitate a methodical approach to evaluation and treatment. Management strategies for these multifaceted injuries attempt to balance the restoration of stability with maintenance of function through the merging of operative and nonoperative means. The operative methods include repair, repair plus augmentation, or reconstruction of injured structures combined with bracing and rehabilitation in the short term. Nonoperative treatment is usually indicated for partial (grade II) ligament tears and occasionally for initial treatment in special circumstances. The ultimate goal of treatment is to return the patient to pre-injury employment or activity with the hope of delaying post-traumatic arthritis. The purpose of this manuscript is to 1) classify for the purposes of treatment for the spectrum of ligament tears included in the term “multiligamentous knee injury (MLKI),” 2) identify the reported incidence of these relatively infrequent injuries, and 3) propose a surgical treatment algorithm based upon the review of case series literature and clinical experience to assist decision-making when faced with this difficult problem.

DEFINITION
Prior to proposing an algorithm for surgical treatment, an attempt must be made to further define the subset of knee ligamentous injuries to be included for treatment. Review of the existing published literature reveals numerous descriptions of various treatment options for patients presenting with more than one ligament injury in the knee, but it is difficult to draw any firm conclusions from these studies due to small sample sizes, heterogeneous injury mechanisms and patterns, variable surgical techniques, inconsistent rehabilitation protocols, and lack of control groups or long term follow-up.1-3

For the purposes of this proposed treatment algorithm, the four major ligamentous stabilizers of the knee will be the anterior cruciate ligament (ACL), the posterior cruciate ligament (PCL), the medial collateral ligament (MCL), and the lateral collateral ligament (LCL), and a patient with MLKI will be defined as one complete cruciate tear (grade III) plus a partial or complete collateral tear (grade II or III) or a partial or complete tear of the other cruciate (grade II or III). Knee dislocations will be defined as complete tears of both cruciates (grade III) plus a complete collateral tear (grade III). Isolated single knee ligament tears will be excluded from this algorithm. The treating clinician should initially identify the most obvious presenting torn ligament, then, when recognizing an associated additional significant partial (grade II) or complete (grade III) ligament tear, follow the algorithm for ACL injury (Figure 1), both cruciate ligament injury (Figure 2), or either collateral ligament injury (Figure 3).

INCIDENCE
Review of published studies analyzing incidence rates of patients with MLKI again reveals a heterogeneous mixture of patient populations, injury mechanisms, and criteria for inclusion making direct comparison essentially impossible. In a prospective cohort of 2,265 patients with knee injuries presenting to five established surgeons at three academic referral centers over an approximate 10 year period, only 11% involved patients with MLKIs. Of these patients with MLKIs, 70.5% involved the ACL and MCL making it the most common presenting pattern and 11.9% involved the ACL and LCL making it the second most common presenting pattern.1 In a retrospective study of 9,749 skiing injuries compiled over 12 seasons at a Wyoming ski resort, 30% involved ligamentous knee injuries. Of these ligamentous knee injuries, combined lesions with specific attention direct-
ed towards concomitant ACL and MCL injuries, accounted for approximately 20% of the knee ligamentous sprains.5

TREATMENT
Optimal treatment of patients with MLKI remains controversial, and many factors must be taken into consideration when individualizing treatment protocols. Patient specific factors include age, pre-injury activity level, medical comorbidities, motivation for rehabilitation, and expectations. Surgeon specific factors include open versus arthroscopic technique, choice of graft type (bone-patellar tendon-bone, hamstring tendon, quadriceps tendon, allograft Achilles tendon, and allograft tibialis tendon), potential neurovascular risks, experience with technique, and post-operative rehabilitation protocol. Injury specific factors include the degree of laxity, acute versus chronic presentation, high versus low energy mechanism, extra-articular injuries, concomitant meniscal articular cartilage injury, limb alignment, and the potential for differential healing based upon the injury patterns for cruciates (avulsions versus midsubstance injuries) and collateral ligaments.

Operative versus Nonoperative Treatment
In the past, treatment of the patient with MLKI consisted of inconsistent periods of immobilization in varying degrees of knee flexion. This method of treatment often led to mixed results due to the inverse correlation between length of immobilization and post-treatment motion. Longer periods of immobilization tended to result in a more stable knee with restricted active and passive range of motion, whereas, shorter periods resulted in more closely achieving normal motion but often with decreased stability. A meta-analysis of 15 case series comparing operative to nonoperative treatment revealed statistically significant improved patient-reported outcomes (Lysholm score of 85.2 versus 66.5), range of motion (123 degrees versus 108 degrees), and a decrease in the amount of flexion contracture (0.5 degrees versus 3.5 degrees) in the operatively treated group. However, no difference existed between the two groups regarding presence of instability, return to work, or return to pre-injury activity level.6 The heterogeneous nature of the injuries and treatments included make interpretation of meta-analysis results relatively unreliable.

Despite the literature showing improved outcomes with operative treatment, nonoperative treatment remains a viable option in select situations.7,8 These options include, but are not limited to, geriatric or inactive patients with co-morbidities that serve as contraindications to surgery as well as trauma patients unable to withstand additional systemic stress from operative intervention. In this setting, outcome expectations must be addressed at the beginning of the treatment period and surgical intervention, if possible, may have to be postponed until a later date in order to address potential instability or loss of motion should such impairments develop. This paper does not further address the nonoperative approach, but it should be remembered that the majority of significant partial tears (grade II) are treated nonoperatively. Thus, understanding how to protect partial tears from excessive forces during rehabilitation is important for avoiding excessive laxity.

Timing of Surgery
No consensus exists in the literature regarding the optimal time to proceed with surgical intervention.3,9 Early surgery allows easier identification of anatomic landmarks and planes with the improved potential for direct repair of injured structures. However, arthroscopic fluid extravasation secondary to capsular injury may occur causing a compartment syndrome, and the risk of postoperative arthrofibrosis may be increased. Delaying surgery allows for decreased swelling, interval healing of the capsule and potentially the collateral ligaments, and increased range of motion. However, extensive scarring...
with resultant loss of anatomic planes may occur contributing to the need for ligamentous augmentation or reconstruction. In general, delaying surgery for 10-14 days allows adequate time for decreased swelling with enough interval capsular healing to allow low pressure arthroscopic evaluation of the knee. During this delay, if initial magnetic resonance imaging (MRI) was not obtained, an MRI should be performed to further clarify the injured structures with attention focused upon the specific location of the injury. Each ligament should be carefully reviewed from femoral to tibial insertion for injury sites, and midsubstance versus bony avulsions at the tibia or femur should be noted. In addition, the MRI assessment of soft tissue and bone injury location has been shown to correlate well with intra-operative findings. With delay of up to 21-28 days, direct repair of bony avulsions or midsubstance collateral ligament injuries can usually be performed, if necessary, with simultaneous arthroscopic treatment of intra-articular injuries and cruciate ligament reconstructions.

**Repair versus Reconstruction**

Many factors influence the surgical treatment of each individual ligament injury, but specific attention should be focused upon the location of the primary injury site within each ligament and the length of time passed since initial injury. Regarding the location of the primary injury site within each ligament, midsubstance cruciate ligament tears (ACL, PCL), at present, are not amenable to repair regardless of the time passed since injury. Reconstruction is recommended in this setting. However, tibial or femoral-sided bone avulsions of the cruciate ligaments may be amenable to repair with screws or sutures. In general, primary repair of non-cruciate ligamentous injuries (MCL, LCL, and posteromedial or posterolateral corner) is a viable option if the surgery is performed within 21-28 days of the date of injury. Reconstruction should be considered if greater than 28 days has passed. In cases of repair, the need for augmentation must be individually assessed both clinically and through intraoperative examination. Thus, the surgeon should be prepared at the time of planned primary repair to be able to both augment as well as reconstruct if necessary.

**Allograft or Autograft**

Choice of autograft versus allograft should be discussed with the patient before surgery with specific attention addressed to the advantages and disadvantages of each. Autografts can be harvested from the ipsilateral or contralateral extremity and include quadriceps tendon, hamstring tendon, or bone-patellar tendon-bone. Allografts allow for a far greater selection of tissues to include the aforementioned tissues as well as Achilles tendon, anterior tibialis tendon, or bone-patellar tendon-bone. Allografts allow for a far greater number of surgeries to include the aforementioned tissues as well as Achilles tendon, anterior tibialis tendon, or posterior tibialis tendon. Use of allografts eliminates donor site morbidity, decreases dissection time, can reduce the number of surgical incisions, and has the potential to reduce postoperative pain and stiffness. However, possible disadvantages include greater cost, the potential for disease transmission, and a delay in incorporation.

**Ligament Options**

The primary goals of treatment are restoration of stability, preservation of motion, and return of function, and each injury must be individually assessed in an attempt to best accomplish these goals. The decision of operative versus nonoperative management of each individual ligament injury is not always straightforward. For instance, an isolated PCL tear with associated 5mm of posterior tibial translation generally allows normal sports function without the need for operative intervention. On the other
hand, an isolated ACL tear with 5mm of associated anterior or tibial translation frequently leads to instability with sporting activities necessitating reconstruction. However, in the setting of a patient with MLKI, operatively addressing the PCL or collateral injuries and delaying ACL reconstruction can potentially lead to similar success rates with a lower risk of postoperative arthrofibrosis compared to addressing all ligamentous injuries at the same time, and subsequent ACL reconstruction is oftentimes not needed. When taking all of these factors into account, it becomes easier to understand the difficulties associated with treatment decisions. This confusing clinical scenario, coupled with the lack of prospective comparative clinical outcome studies, led us to develop a surgical treatment algorithm for patients with MLKI.

If the patient presents with an ACL tear with associated ligamentous injuries, the approach is shown in Figure 1. In the setting of a grade III ACL tear with associated collateral or PCL injury, physical examination both preoperatively and under anesthesia is performed to determine if the associated ligament tear is complete (grade III) or incomplete (grade II). The difference between complete versus incomplete injury is defined by the presence or absence of significant abnormal laxity to valgus (MCL) or varus (LCL) stress when the knee is in full extension (zero degrees) and comparing to the contralateral normal knee. Since many patients with multiligamentous injuries may not be able to obtain full extension pre-operatively, the exam under anesthesia is a critical element to surgical decision making. If the associated injury is complete, the impairment should be addressed surgically at the time of ACL reconstruction. Correlating physical examination findings with MRI aids the surgical approach in identifying the site for repair of collateral ligaments. If the associated injury is incomplete, the patient may be treated with rehabilitation following ACL reconstruction.

If the patient presents with excessive anterior-posterior laxity indicating complete tear of one cruciate ligament and injury to the other cruciate ligament is suspected, the approach is shown in Figure 2. In the setting of injury to both cruciate ligaments, again an attempt must be made to differentiate between complete and incomplete injuries utilizing physical examination (preoperatively and under anesthesia), MRI, and arthroscopic evaluation. If both the ACL and PCL are determined to be completely disrupted (grade III), the PCL should be addressed surgically with either simultaneous ACL reconstruction or delayed ACL reconstruction in the future based upon predicted potential for ACL instability in activities of daily living. Any complete collateral ligament injuries should also be addressed operatively. In the setting of one complete cruciate ligament injury combined with an incomplete injury to the other cruciate ligament, the cruciate ligament with the complete injury should be addressed surgically with initial nonoperative treatment of the incompletely injured cruciate ligament. Again, complete collateral ligament injuries should be addressed operatively.

Not infrequently, the patient with MLKI presents with complete collateral ligament injury with excessive laxity at full extension. This finding should tip the examiner that a cruciate ligament is probably torn, and complete knee evaluation with MRI is indicated. Figure 3 outlines the approach to patients presenting with this scenario. In the setting of complete collateral ligament injuries, care must also be taken to evaluate the posteromedial corner and the posterolateral corner of the knee. These injuries should also be addressed operatively as this impairment constitutes part of the spectrum of stability imparted by the collateral ligaments. It must be remembered that collateral ligament injuries frequently display interval healing during the time from injury to operative treatment. Therefore, the best time to assess the completeness of a collateral ligament injury is during the preoperative exam under anesthesia. If the tear is determined to be complete, operative treatment is recommended at the site of injury. The operative approach should be determined after reviewing the MRI to determine the location of injury. Careful review of preoperative imaging studies can limit the size and number of incisions needed to address pertinent pathology.

Published outcomes following treatment of patients with MLKI are mostly based upon procedural oriented studies and consist of case series. Results are surgeon dependent with variable rehabilitation protocols and no control groups. It is difficult to make comparisons amongst different techniques due to the broad number of procedures performed, the acute versus chronic nature of the injuries at the time of treatment, the combination of repair versus augmentation versus reconstruction methods, the use of allograft versus autograft, the presence of associated articular cartilage and meniscal injuries, and the lack of multivariable analysis. Thus, the approach presented represents interpretation of existing literature and experience with these complex injuries in an academic sports medicine practice setting.
REHABILITATION GUIDELINES
Postoperative rehabilitation guidelines must be individualized for each patient, and a multidisciplinary approach is vital for successful outcomes. Communication amongst the various treatment teams is the most important factor, and the surgeon and therapist must frequently re-evaluate the progress of each patient. As always, the rehabilitation plan should first be addressed preoperatively with the patient engaging in a discussion of expectations for return to activity and function. This discussion should set realistic goals based upon the severity of initial injury.

The initial postoperative rehabilitation plan must take into account strength of fixation, balance the concerns for stiffness versus postoperative laxity, and provide protection when needed. The strength of fixation should be maximized intra-operatively by the surgeon and stability re-assessed while the patient is still under anesthesia. These findings should then be communicated to the therapy team. The presence of associated meniscal or articular cartilage injuries should also be communicated, as well as the plan for initial postoperative weight-bearing. In general, surgical treatment of PCL injuries requires a brief period of immobilization, and collateral ligament injuries require protective bracing. In cases of PCL or collateral ligament injury, weight-bearing is often delayed to allow more time for healing. In cases of ACL reconstruction, early motion generally results in a better outcome.

All of these factors must be taken into account with the need for ligament immobilization, protection, and motion balanced against each other for an individualized treatment plan.

CONCLUSION
Multiligamentous knee injuries include a wide spectrum of pathology and represent a difficult clinical problem. A methodical approach must be implemented for each encountered injury pattern, and realistic goals must be established with the patient at the onset of intervention. Treatment remains controversial due to the lack of published high level evidence (prospective comparative clinical outcome studies), and results reported thus far are not patient-reported with validated outcomes. The decisions of operative versus nonoperative management, timing of surgery, repair versus reconstruction, use of allograft versus autograft, choice of which ligaments to treat, and rehabilitation protocols must be individualized to expected outcomes. Use of proposed surgical algorithms may facilitate clinical decision making in an attempt to restore stability, preserve function, and maximize return to activity.

REFERENCES
ABSTRACT

The knee is a mobile functional anatomical unit which plays a key role in recreational function. In the last three decades, the knee has received a great deal of attention in the sports medicine literature, particularly in respect to isolated ligament pathology and management. In reference to combined multiple ligament pathology, a more limited number of articles exist, and indeed lead to confusing management. Although hundreds of publications address the topic of surgical correction of the anterior cruciate ligament (ACL), debate continues regarding clinical intervention for the patient with combined ACL and medial collateral ligament (MCL) management. Issues exist which the clinician must consider, including which structures require repair, timing of surgical intervention, and rehabilitation approaches. This article will attempt to define a treatment algorithm for the clinician to consider with simultaneous injury to the ACL and MCL.
INTRODUCTION

The evolution of rehabilitation over the last 20 years has been to establish pathways with a foundation using evidence-based principles. However, if one uses the classic definition of evidence-based protocols with regards to the multiple ligament knee injury (MLKI), the results will be restricted when compared to the depth of structures such as the anterior cruciate ligament (ACL) or posterior cruciate ligament (PCL) in isolation. Multiple authors have demonstrated results of non-operative intervention in the isolated medial collateral ligament (MCL) injury model. These studies have investigated parameters such as surgical correction, immobilization, and early functional rehabilitation in the patient with an isolated MCL injury. The reported outcome appears favorable, however, a small percentage of patients continue to demonstrate residual instability at four years post injury. The model of both early motion and immobilization result in similar success with return to functional activity. Lundberg et al reported a 74% return to normal knee function by three months post injury; 87% had return to normal function by four years; and by ten years only 13% demonstrated medial compartment osteoarthritic (OA) changes. Nonoperative and operative treatments of patients with MCL injuries lead to equally positive results. Additionally, MCL ruptures need not be treated operatively when the ACL is reconstructed in the early phase.

The evolution of management of multiple ligament injuries to the knee received greater attention following O’Donoghue’s 1970 description of the “Unhappy Triad Injury.” He reported on the relationship of MCL, ACL, and medial meniscus injuries as they relate to sport specific functions. These injuries represent a complex mechanical pathology which initiated a debate over the correct surgical management in an era of sports medicine when both surgical and rehabilitation procedures where in their infancy. O’Donoghue was one of the first authors to discuss the effects of the valgus force at the knee from loading response through mid-stance, and the resultant strain to the injured MCL. He further described the anatomical relationship of the MCL to the medial meniscus and proposed gait demands as an indicator for treatment intervention.

Review of Injury Mechanism and Ligament Evaluation

Injuries to the knee follow a specific and well-defined pattern, resulting in high force production until tissue failure occurs. Multiple studies describe the key mechanism as an externally applied valgus force with the foot fixed at the distal segment. The application of a valgus force at the knee results in ACL/MCL tears, lateral compartment bone bruise, and lateral meniscus tear. Grood et al described the primary restraint ligaments and secondary structures to function like cables on a bridge, with progressive force application causing an increase in the strain that is applied to the primary ligament, as well as the secondary stabilizers. At 20 degrees of knee flexion, the MCL is the primary stabilizer to the medial compartment, with the posterior medial capsule providing a critical secondary role.

The physical exam defines the extent of pathology to the medial ligament system and directs the clinician in the establishment of the initial phase of treatment. Evaluation of the medial compartment requires practiced skill of the clinician to control the direction of the evaluation forces and unwanted secondary motion. Avoiding tibial rotation while evaluating valgus rotation is critical to a reliable and valid evaluation technique. If external tibial rotation occurs with the evaluation, ensuing tension in the posterior medial corner will have a negative result on the evaluation. A bilateral comparison serves to provide a baseline for the clinician when testing the non-involved extremity first.

With a medial injury, three potential findings exist:
- Medial pain with no increase in translation = grade 1
- Medial pain with increased translation up to 5 mm = grade 2
- Medial pain with increased translation in excess of 10 mm = grade 3

If ACL or PCL pathology concurrently exists with the MCL pathology, valgus translation will be increased in the 0 degree position and in hyperextension. The related cruciate injury will be corroborated by a positive result with either the Lachman’s test or appropriate PCL laxity test maneuver.

The authors suggest that a confirming magnetic resonance imaging (MRI) be performed to identify all possible internal joint derangements. This completes the loop and aids the clinician in the development of a comprehensive treatment program to include a conservative component and staging of the surgical procedure to assure higher success rate.

INITIAL TREATMENT ALGORITHM:
THE CINCINNATI EXPERIENCE

Establishing a treatment pathway is based on a tiered approach with the dependent variables including but not
limited to ACL tear, degree of MCL tear, medial or lateral meniscus tear, chondral surface damage, and capsular injury. The period of time between injury and surgery also varies based on the severity of the injury and tissues involved. Control of the post-injury sequelae of range of motion (ROM), muscle control, allowance of time for scarring of the MCL, and protection of the region of the bone bruise will be factors in determining the time of surgical correction.

**Grade 1 MCL** – Injury with or without meniscus damage ACL surgery within one week; no pre-surgery motion restriction.

**Grade 2 MCL** – Injury with or without meniscus damage ACL surgery within two weeks; a seven day period of motion limitation (brace locked at 30 degrees but full motion performed in rehabilitation on a daily basis, and after seven days the brace is unlocked to full motion).

**Grade 3 MCL** – Injury with or without meniscus damage ACL surgery at three weeks with a 10 day motion restriction period (brace locked at 30 degrees and full motion is performed in rehabilitation starting day seven after injury, and brace unlocked after 14 days).

Among those patients with ACL/MCL injuries, two distinct groups exist, each with different prognoses related to return of motion based on the location of the MCL disruption. Patients with double-ligament injuries, where the MCL lesion is proximal, should be managed very aggressively to regain motion.

The consequence of the bone bruise when present will result in restriction to weight bearing forces during this phase of the rehabilitation program. From the time of the initial injury until the completion of the post surgical rehabilitation phase, weight bearing is controlled. The post-surgical weight bearing will be addressed in a later section. Likewise, meniscus involvement ranks higher in priority in reference to weight bearing, an MRI evaluation can identify the degree, position, and compartment of the meniscus tear, and may dictate weight-bearing progression with lateral meniscus requiring greater protection. The restriction for weight bearing post surgery would also be premised on the meniscus compartment and tear location.

**NON-OPERATIVE TREATMENT**
Currently, the standard of care for the patient with MLKI is surgical reconstruction of disrupted ligaments and repair of the collateral ligaments when complete disruption of the fibers occurs. However, because of the complexity of the patient with MLKI, often concomitant neurological or vascular issues can arise delaying or preventing surgical intervention all together. Wascher et al\(^{10}\) cited a 10% incidence of life-threatening chest, abdominal, and head injuries in the patient with MLKI.\(^{10}\) In addition, other musculoskeletal issues can occur to the surrounding hip, femur, and tibia. Of particular concern, is the popliteal artery and peroneal nerve, which can be easily affected with varus force at time of injury. Both structures need to be assessed at time of injury to ensure immediate care.

Because of these issues and the fact that every patient should be treated on an individual basis, select times exist when surgery on these patients is not performed. In these cases, the definitive treatment is not well-defined. Treatments for this population range from extended immobilization and external fixators for complete dislocations to immediate motion, preferring laxity to scarring of tissue. The decision making process is highly dependent on the degree of injury, patient type, and surgeon's preference. In a young and athletic population, however, surgical correction is almost always recommended.

**POST-OPERATIVE REHABILITATION**

**PHASE I: Program Objectives**
The key is to identify the rehabilitation components that the therapist must address in order to restore normal function, and then progressing the exercise program to higher levels of function until the patient achieves an optimal level of function. The therapist considers a staged approach, and must assess the interaction of how one component is influenced by another. The components of the program include:

- Regulate post-surgical pain to avoid influence on ROM and muscle contraction.
- Reduce post-surgical hemarthrosis to avoid muscle shutdown and arthrofibrosis.
- Re-establish joint ROM as the primary objective in order to avoid deleterious motion loss.
- Advance weight bearing and development of normal gait mechanics without affecting the biological graft.
- Establish early exercise sequences to recondition the muscular system while minimizing risk to biological graft.
- Re-train the mechanoreceptor system through proprioception program.
• Establish subjective and objective data to identify deviations from norm to minimize influence on the outcome.
• Establish a functional algorithm to verify functional progression.
• Progressive functional return to activity and sport.

In addition, outcome success is dependent on the understanding that patients have intrinsic and extrinsic variable factors that influence the level of activity to which they return. Intrinsic factors may include, but not be limited to, tissue type, muscle type, potential for excessive scar formation, general medical well being, osseous alignment, lower extremity mechanics, and compliance to program. Extrinsic variables include, but may not be limited to, social habits, use of nicotine products, environmental situations, and economical reality. Rehabilitation requires the therapist to address many of these issues.1,11

Re-establishing Range of Motion
The first goal in the rehabilitation program is obtaining full ROM. The use of continuous passive motion (CPM) after surgical procedures arose from a combination of animal and human studies in the late 70’s and early 80’s.12-15 The primary focus of these studies was to assess forces applied by early motion on the biological graft and surrounding tissues. This was a 180 degree shift in post surgical management. The rationale for the changing philosophy was the morbidity of the joint associated with prolonged immobilization. Early studies were undertaken to determine if early use of CPM would provide a positive influence on graft re-vascularization and collagen regeneration, but findings demonstrated no cause and effect relationship. The positive findings identified with these studies included earlier redevelopment of ROM, decreased post surgical pain, decreased joint hemarthrosis, decreased scar tissue, and maintaining viability of the articular cartilage in the joint.

Currently, the recommendation for the use of a CPM machine immediately post surgery is 10 to 12 hours/day until the unit is at maximum range. Most patients are able to tolerate a gradual increase in motion, discontinuing the unit after seven to 10 days. On average, the patients adjust their motion 10 to 15 degrees a day. If CPM is not desired, self-ranging exercise can be preformed utilizing the contralateral extremity on an hourly basis.

Weight Bearing
The second goal in the early rehabilitation period is the progression of the weight bearing process. Again, a range of weight bearing progression exists in current protocols, some of which advocate immediate full weight-bearing in a locked extension brace, while others advocate the use of crutches for upwards of four to five weeks. The concept of immediate full weight bearing programs has prevailed with the thought that the weight bearing facilitates faster extensor mechanism return. No data appears to support this claim and the patient may accommodate for a poor extensor mechanism by ambulating in a leg vault gait pattern.16,17 Allowing an asymmetrical gait pattern secondary to extensor mechanism weakness leads to the potential development of a recurvatum at the midstance position. This recurvatum may result in an unwarranted side-effect of a prolonged altered gait pattern at midstance, due to poor extensor eccentric control as the knee attempts to go into flexion of 15 to 20 degrees. Our approach has evolved to allow immediate partial weight bearing in either a protective ROM device or no brace at all. From the initial phase, gait mechanics are retrained without compensation beginning on the first day. Concurrently, the patient is placed in a gait training program to emphasis the proper position and strength. To progress the weight bearing program, the clinician must assess the factors that influence the gait pattern and the biological graft:

• Motion must progress as weight bearing is advanced.
• Extensor strength is able to control 0 degrees ROM without extensor lag.
• Joint effusion is resolving as demonstrated by objective measures.
• Joint arthrometer evaluation is not significantly changed on a test retest basis.
• Pain control has been achieved to avoid sympathetic maintained pain patterns.

A post-surgical knee orthosis is fitted at the time of surgery to allow for early weight bearing with crutch support. The brace is unlocked to allow for normal gait mechanics and avoidance of deviations commonly seen with patients in a locked brace. These deviations include a vaulting gait, circumduction of the involved lower extremity, or avoidance of weight bearing on the limb.

Muscle Re-education
Re-establishing muscle control after joint surgery over the last 20 years has changed dramatically and has many different pathways. This process of re-establishing muscle control is initiated immediately, compared to 30 years ago when the patient was casted for six weeks or longer. The evolution has been brought about by basic scientific stud-
ies allowing a better understanding of joint compression forces, exercises forces applied to the ligament, improved surgical techniques, and avoiding joint morbidity effects.

Initially, the goal is to simply retard the effects that joint hemarthrosis and surgical pain have on the muscle by causing reflex shutdown. The classic use of isometrics, open chain isotonics such as active range of motion with the weight of the ankle, and straight leg raises can be beneficial. These exercises are generally low load and independently may not prevent the disuse muscle atrophy that affects the knee joint.

Over the years many exercise approaches have been advocated and in some cases are associated with several complications. Although the trend is to accelerate patients, patellar tendonitis is common with a 9% occurrence rate. Of greater concern is the development of patello-femoral arthritis, which has been reported in a 7% to 51% range in association with ACL reconstructions. Early phase extensor mechanism exercises may generate large forces across the articular surfaces of the patella. Rehabilitation, therefore, must not only account for the healing graft, but also patellar protection. Patellar degeneration is unpredictable and varies among patients especially with reference to age range. Shino et al reported that on second look arthroscopy 51% of allograft patients demonstrated patellar changes, yet only 17% of the patients reported subjective complaints. Autograft studies describe subjective complaints ranging from 7% to 29%. Another associated complication leading to patella complaints is infra-patellar contracture syndrome, described as a distal migration of the patella secondary to scaring in the fat pad, or a shortening of the patellar tendon, which can occur after surgery. In this scenario, the patella is displaced onto the troclear surface, consequently increasing patellar compression and shear load. Maintaining adequate extensor mechanism control in the zero degree position can help avoid these complications. In addition, emphasizing early patellar mobilization immediately following surgery can help to prevent infra-patellar contracture later in the rehabilitation process.

In order to both understand the process of neurologically induced muscle shutdown and to develop rational treatment approaches, the therapist must understand the reflex inhibitory mechanism. The key to this process is historical and well defined. Newton identified four neural components to the mechanoreceptor system; these either inhibit or facilitate muscular response to input. Kennedy et al demonstrated the influence of joint pressure on mechanoreceptors as inhibitors resulting in extensor mechanism shutdown; however, this study did not quantify muscle loss percentages. In 1984, the senior author described how a mere 70 cc’s of injected saline reduced isometric output of the knee by 37% in a normal joint.

In the last 15 years the use of muscle stimulation has gained wider acceptance and is now considered part of standard care. Attempting to achieve two objectives, the rehabilitation program utilizes electrical currents in an attempt to reduce the influence of pain as well as re-establish muscle control of joint motion. Immediately following injury, the use of a stimulation unit to modulate pain helps to provide control of a patient’s subjective complaints. This control is achieved using TENS type stimulation, such as an Empi 300PV system (Empi, St. Paul, MN) utilized on a 24 hour a day basis. Secondly, the Empi 300 PV is programmed so that voluntary muscle control of the extensor mechanism is facilitated with the assistance of muscle stimulation applied to the vastus medialis oblique muscle region and the proximal location of the femoral nerve. The goal of this program is to augment and produce a stronger contraction of the extensor mechanism. As a patient’s program progresses and the extensor mechanism becomes able to achieve a 0 degree position, the patient is moved to more closed chain functional positions to replicate challenges of maintaining the knee in ideal positions for activities of daily living and sports.

**PHASE II: Program Objectives**

Typically during the six to 12 week time period, patients graduate to advanced neuromuscular and functional training. At this time, exercise intensity is increased to allow for the muscle adaptation, a requisite for sport-specific demands. Areas of importance and emphasis during this time period are muscle strength, power, endurance, and control. Aspects of acceleration, deceleration, and reflex response are slowly integrated into the rehabilitation program. The progression of training should increase the duration of the exercise session first, then increase the intensity of the workload, and finally integrate functional training with sport specific drills.

**Muscle Re-Education**

During rehabilitation, emphasis should be placed on training the entire kinetic chain, not just the involved lower extremity. Proximal stabilization is of particular importance to the athlete and should be incorporated from the early postoperative phase until return to sport. The hips,
pelvis, lumbar spine, and abdominal musculature are areas of primary focus. Straight leg raises are initiated early and progress to higher resistance, providing early stage training but limited functional carry over. In essence, these exercises are isometric to the vast group; the long lever arm minimizes the total amount of resistance.

To initiate training for rapid response time of the muscles that are required to control tibial translation involves incorporating high-speed training of the proximal stabilizers of the hip and pelvis. This proximal strategy is part of the core stabilization program. Core muscle group training includes bridges using bilateral lower extremities, which progress to bridges with single limb support and alternate leg extension. Single leg bridges are held for 10 seconds at a time. Single leg bridges are a more advanced core stability exercise and should be performed for both involved and uninvolved extremities. At this point, side-lying bridges should also have been implemented, advancing by abducting the contra-lateral arm and using weights to increase the balance component. It is important to continuously reinforce proper lumbo-pelvic positioning while avoiding faulty patterns. Abdominal and oblique muscle exercise advancement is paramount during this phase of rehabilitation. Dynamic rotation, plyometric sit-ups, and power training are progressed at this time. All of these exercises can be performed in supine, standing, and in sport and position-specific athletic positions, all of which emphasize total body control and stabilization.

Open kinetic chain knee exercises are continued during this phase. Both isotonic workloads and isokinetic training sessions are helpful. Care must be taken to protect the healing graft and to avoid patellofemoral joint irritation. Isotonic extension work should be limited to arc of 90-30 degrees, and heavy resistance loads should be avoided. Hamstring workload is not limited, unless a posterolateral capsule or meniscal involvement exist. The senior author has advocated an approach utilizing higher velocity for evaluation and training to protect the patella and gait. 27,28

In closed chain training 0 degree stops are used to prevent knee hyperextension. Markolf et al 29 reported that hyperextension ROM placed the highest forces on the ACL. 29

Closed kinetic chain training also plays a primary role in ACL rehabilitation. This rationale is based on the performance of functional training and strengthening simulating both sport specific movement and those associated with activities of daily living. The literature supports this training based on data from both cadaveric and in vivo models. Both Beynnon et al30 (performing in vivo measurement) and Wilk et al31 (by mechanical methods) predicted low strain on the ACL in the closed chain position. They also reported that the quadriceps and hamstrings muscles co-contract to protect the ACL graft against strain. 30,31 Others also report that the closed chain position allows exercises for early resistance training to the lower extremity. 32

Particular emphasis should be placed on single leg training to enhance neuromuscular control of the knee. Focus on postural awareness and postural stability in the single limb supported position is paramount for an athlete to return to competition. Athletes in competition spend a critical amount of time in the single leg position, executing movements such as running, cutting, pivoting, jumping as well as various acceleration and deceleration maneuvers. As part of the rehabilitation continuum to successfully return an athlete to their prior competitive level, training and assessment of proper landing mechanics is performed early in the program. In patients with weak proximal joint segments, valgus (at the knee) and internal rotation (at the hip) increase the strain on the ACL. Landing training begins with the eccentric step down program and builds to dynamic and responsive stability in the single leg exercise position. 33

Training in the single leg position is progressed from a very controlled environment, focusing on balance in addition to posture and control of the entire kinetic chain. Dynamic stability is gradually introduced by altering the base of support, involving the upper extremities, incorporating sport specific activities, and lastly implementing rotational components to the program. Kicking exercises with resistive bands at high speeds can be performed at the five to six week time period as a rhythmic stabilization drill. Lunging exercises are progressed by means of altering surfaces, providing manual perturbations, and eventually, performing sport specific tasks. Single limb training promotes stabilization of the entire lower extremity and should be performed concurrently with the hip/pelvis/trunk stabilization program previously described. The athlete must learn to control the body as it transitions from one point to the next, including forward, backward, and lateral movements.

Between weeks six and 12, overall strengthening and stabilization of the lower extremity continues; however, speed of performance is also progressively emphasized. Many exercise variations exist that can be implemented early that slowly progress toward higher speed maneuvers.
Elastic bands, lunges, and many stepping and footwork drills can progress toward higher speeds. Over time, repetitions and durations of exercise should increase; ensuring a combination of both submaximal and aerobic training. The critical element at this time period is endurance activity to counterbalance muscle fatigue.

PHASE III: Return to Activity

Return to activity, on the average, is a bell shaped curve. The range of return is 12 weeks for the hypo-elastic patient and up to 12 months for the hyper-elastic patient. On average, six months serves as our mean time for a safe return to activity, based on biological healing of the graft. For return to activity the following objective and subjective evaluation should occur:

1. Subjective rating on the International Knee Documentation Committee (IKDC) scoring system as compared to pre-injury status
2. Joint arthrometer score of 3 mm or less (patients above this parameter may be held longer)
3. Objective muscle scoring within 85% of the contralateral extremity
4. Functional hop scores within 85% of the contralateral extremity
5. Progressive drill re-enactment to simulate activity anticipated upon return to sports
6. Confidence by patient to psychologically perform skill specific activity

CONCLUSION

Management of the patient with injury to both the ACL and the MCL can become complicated and confusing. As a number of knee injuries do involve multiple ligaments, especially in sports, it is important to use a well thought out program for rehabilitation. Focus should be placed on both ligaments, so that rehabilitation of one does not detrimentally affect rehabilitation of the other. This manuscript presented a treatment approach using an algorithm which includes focusing on increasing range of motion, developing normal gait mechanics, reconditioning the muscular system, and progressing functional return to activity and sport.

REFERENCES


INVITED CLINICAL COMMENTARY

SURGICAL TREATMENT AND REHABILITATION OF COMBINED COMPLEX LIGAMENT INJURIES

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ABSTRACT

This article is a description of the surgical treatment and rehabilitation of combined complex ligament injuries. A background will be provided, and information on the combined complex knee injuries, selected aspects of surgical treatments, and rehabilitation strategies will be presented. Combined complex ligament injuries are devastating injuries and are not very common compared to other knee injuries. No meta-analysis or systematic review studies exist regarding the best treatments for these patients. This article’s emphasis is on the stages in the rehabilitation program with documentation of the scientific and clinical rationale for the treatment techniques in each stage. Treatment interventions are described and documented with the limited evidence available in treating these patients. Guidelines for treatment, surgery, and a clinical protocol for treating patients with combined complex ligament injuries are provided for the practicing clinician to use as a template for treating these complicated patients.

Key Words: knee dislocation, multi-ligament knee injury

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INTRODUCTION
Historically, knee dislocation and traumatic multi-ligament knee injury (MLKI) was usually managed with prolonged immobilization. The tradeoff for stability was significant knee stiffness. Surgical intervention was performed, not to restore limb function, but as an attempt to avoid the gangrene and life-threatening sepsis which all too often followed vascular compromise in the pre-antibiotic era. In 1824, Sir Astley Cooper stated that “there are scarcely any accidents to which the body is liable, which more imperiously demand immediate amputation than these.”

Although the first reported description of surgical repair was by Thomas Annandale in 1881, few advances were made for many decades. Improved techniques to address vascular injury evolved during the Korean and Vietnam Wars and made limb salvage possible. Then in 1963, Kennedy published the first attempt to systematically define the pathophysiology of the dislocated or multi-ligament injured knee, and his work stimulated interest in the problem. Initial reports suggested that reasonable outcomes could be obtained with non-operative management, and that those results were comparable to surgical intervention. However, during that era, the typical surgical treatment involved the re-approximation of the cruciate and collateral ligaments with suture, rather than reconstruction with grafts, as well as other techniques that are now of historical interest only. As the technique and success rate of single cruciate ligament reconstruction evolved, so too did application of reconstruction occur for patients with MLKI. More recent authors have consistently reported superior results with an approach combining reconstruction of cruciate ligament insufficiency with repair or reconstruction of collateral ligament disruption.

The decision for surgical versus non-operative treatment must still be individualized, however, as not all patients are candidates for operative intervention. Success is dependent on not only that portion of treatment which occurs in the operating room, but also that which is related to patient enthusiasm and compliance afterward. Both the ability of the surgeon to manage a complex and demanding procedure and the full cooperation of the patient during a lengthy convalescence are mandatory. Elements such as patient age and fitness, associated injuries, pre-injury level of function, and availability of appropriate physical therapy must be considered. For example, MLKI’s sustained during athletic participation typically occur in well-conditioned individuals who are already familiar with physical training and rehabilitation and are motivated to return to a level of function for which knee stability is crucial. In contrast, the risk/benefit ratio for multiple trauma patients is higher. The high-energy dislocations of motor vehicle injury are more likely to involve individuals with multi-system injury or those unaccustomed to regular physical exercise. These individuals may be unable or unmotivated to participate in the lengthy and arduous rehabilitation necessary to maximize their recovery. Rather than improving their prognosis, well-intentioned surgical stabilization may instead increase the likelihood of permanent disabling knee stiffness.

Four guiding principles apply to the elective surgical treatment of MLKI:
1. Never jeopardize the life of the patient or the viability of the limb to improve the chance of obtaining a stable knee.
2. Residual laxity is easier to treat than arthrofibrosis.
3. When in doubt regarding patient fitness, compliance, coping skills, or tissue quality - delay or avoid surgery.
4. The goal of surgery, regardless of pathology, is the restoration of all instability patterns with adequate tissue and methods of fixation such that range of motion (ROM) can be allowed early in the postoperative course.

Although a detailed description of surgical technique is beyond the scope of this paper, some specific points that bear on postoperative recovery and rehabilitation merit emphasis. Most of the same principles also apply to patients where non-operative treatment is elected. Optimal treatment of the patient with MLKI requires a team approach. The physical therapist should read and understand the operative report, comprehend the ramifications of specific aspects of the surgical procedure, and communicate with the surgeon before beginning treatment.

No uniformity of opinion exists with respect to the optimal timing of surgery and the specifics of ligament repair/reconstruction. Shelbourne and Carr have recommended initial non-operative treatment for anterior cruciate ligament (ACL)/posterior cruciate ligament (PCL)/medial collateral ligament (MCL) injuries when PCL laxity is grade II or less and PCL reconstruction alone if PCL laxity is grade III. Their approach is predicated on the belief that the PCL and MCL have “intrinsic” abilities to heal, that residual laxity is preferable to stiffness, and that...
ACL reconstruction can be performed electively if necessary as a secondary procedure once ROM is re-established.13 Others have recommended that most patients with MLKI be treated by initial brace immobilization followed by simultaneous arthroscopic bi-cruciate ligament reconstruction in 4 to 6 weeks.14,20,30-35 Any residual collateral ligament laxity is later treated with reconstructive techniques.

Currently, most authors recommend simultaneous bi-cruciate and collateral ligament reconstruction/repair performed at approximately 14 days from injury unless extenuating circumstances exist.16,17,24,25,28 By this time, post-injury edema and the acute post-traumatic inflammatory response will have largely subsided and the ROM will have been at least partially restored. However, anatomic definition of the collateral ligaments and capsule still remains possible. The senior author has consistently followed this approach and believes that bi-cruciate ligament reconstruction allows the most accurate centering of the tibia on the femur and minimizes stress on repaired collateral ligaments; that cruciate and collateral reconstructions are complimentary, and thus best performed during a single surgery; and that delayed reconstruction of significant structural injury to the posterior medial or posterior lateral corners can not consistently match the quality of the end result obtained with acute surgical treatment. However, this approach assumes exacting surgical technique, tissue fixation that will tolerate aggressive rehabilitation, and appropriate patient compliance.

Although the majority of patients with MLKI can be managed on an elective basis, immediate surgery is indicated when the injury is compound (a wound communicates through the skin with the deep tissue or joint);15,32,52 associated vascular injury occurs;42-44 displaced intra-articular fractures exist requiring open reduction and internal fixation;45-47 and a complex dislocation occurs (usually posterolateral), wherein interposed capsule prevents concentric reduction of the dislocation.48-51 In these instances, definitive attention to the ligament pathology is delayed to be treated on an elective basis once the health of the limb is assured.

Three additional scenarios may mandate surgical intervention earlier than usual.

First, abnormally displaced structures (locked meniscus, flipped collateral ligaments);48 second, cruciate ligament avulsions from bone (as opposed to the typical interstitial disruption);15,32,52 and third, extensor mechanism disruption (quadriceps or infrapatellar tendon rupture).28

When early definitive surgery is not advisable, application of an external fixator or a hinged cast brace may be recommended. The spanning external fixator is often the best choice for patients who will be treated non-operatively. This technique provides good stability of the knee joint, is readily adjustable, and allows excellent access to open wounds and assessment of neurovascular status. Fixation pins must be placed far enough away from the joint and in such a manner that the pin tracks will not compromise incision placement for future knee surgery. If a non-operative approach is elected as the definitive treatment, the external fixator is maintained in place for six weeks before ROM exercises are begun. Serial radiographs should be obtained to confirm that a perfectly concentric reduction has not been lost during the period of immobilization. Recently, articulated hinged external fixation has also been proposed as a routine supplement for post-operative protection.53

Several graft options are available for cruciate ligament reconstruction. Ipsilateral autografts (patellar tendon for the PCL and semitendinosis/gracilis for the ACL) can be used, but harvest of these grafts increases the morbidity of an already severely traumatized knee. Contralateral autografts can be utilized, especially if the patient will not allow the use of allograft tissue, but their use does, at least theoretically, compromise a perfect knee and harvesting requires additional operative time. The success rates obtained using allograft tissue in the reconstruction of isolated ACL and PCL injuries has been documented to approach that of autografts, and their use in the multiple-ligament-injured knee has decided advantages.16,25,54-57 Donor site morbidity is eliminated and a second surgeon or assistant can prepare the grafts while the primary surgeon prepares the knee, thus saving significant operative time. The only drawbacks to allograft use are potential disease transmission, limited availability, and cost.54,58-60 The patellar tendon is frequently utilized for ACL reconstruction and the Achilles tendon for PCL reconstruction. However, quadriceps, tibialis anterior, tibialis posterior, and semitendinosus muscle tendon allografts are also commercially available and can be utilized for either cruciate or collateral ligament reconstructions.

**SURGICAL ALGORITHM**

A suggested surgical algorithm for patients with MLKI is as follows:
1. A focused evaluation of the pattern and magnitude of ligament laxity is repeated under anesthesia to confirm the initial clinical impression and the findings suggested by pre-operative magnetic resonance imaging (MRI). Although MRI is an important tool to assist in both the diagnosis and planning of these complex injuries, the test is neither 100% sensitive nor specific. Special MRI technique is required to sensitively assess the posterolateral corner, which is not well seen on standard images. Even the best MRI study can occasionally be misleading, with partial PCL or collateral ligament injury misrepresented as being complete.

2. Arthroscopy is used to confirm the expected pathology and to address meniscal or chondral injury. If residual concerns exist about the integrity of the capsule to contain fluid, or if any intra-operative indication of fluid extravasation exist, the arthroscopy is performed dry.

3. Incisions to expose and isolate collateral ligament pathology are made. The specific incision chosen depends upon the structures that are to be repaired or reconstructed. It is important to maintain the widest possible spacing of incisions to minimize wound healing complications.

4. Controversy continues regarding the optimal technique of both ACL and PCL reconstruction. Traditionally, PCL reconstruction has been performed utilizing a graft routed into and out of the knee via tibial and femoral tunnels. If this trans-tibial technique is utilized, the tunnel must be positioned as vertically as possible for optimal mechanical advantage and to avoid the tibial tunnel made for ACL reconstruction. The tunnel should exit the posterior cortex of the tibia well distal to the PCL insertion. Several authors currently advocate PCL reconstruction performed with the graft fixated directly to it's tibial insertion site, thus avoiding the need for the graft to traverse the “killer turn” from a tibial tunnel into the knee. This “inlay” technique is performed via a posterior medial incision and direct soft tissue dissection to reach the popliteal fossa. Still other authors have advocated the use of double-bundle, rather than single-strand, grafts in order to best replicate the normal PCL anatomy of separate anterolateral and posteromedial bundles. In this case, two separate tunnels are drilled in the femur, one for each graft strand.

Recently, modifications in the technique of ACL reconstruction have also been suggested. These modifications emphasize the advantage of viewing the femoral insertion from a medial arthroscopic portal to best appreciate that anatomy, and then placing the femoral tunnel low enough on the lateral wall of the intracondylar notch to replicate both functional bundles. This technique places the tunnel closer to 9 or 3 o'clock on the wall of the intracondylar notch, rather than the previously accepted 10 or 2 o'clock position. Such tunnel placement may mandate that the femoral tunnel be drilled separately (through an anteromedial portal with the knee hyperflexed, or with an outside-in guide), rather than by working through the tibial tunnel. It has also been recently proposed that the ACL be reconstructed with separate tibial and femoral tunnels for each of its two functional bundles. Although the advantages of two bundle reconstructions have been demonstrated by several authors in respect to isolated ACL reconstruction, the applicability of this technique, with the far greater complexity and time requirements, has not been tested in respect to more complex knee instabilities.

Generally, the tibial tunnel or inlay site for the PCL is prepared first, followed by the tibial tunnel for the ACL. The femoral tunnels for the PCL and ACL are made subsequently.

5. The PCL is the cornerstone of multi-ligament reconstruction. Once the tunnels are ready, the PCL graft is passed and anchored securely at one end (which may be either the femoral or tibial end, dependent upon the technique utilized). The knee is then cycled through repeated arcs of motion to ensure that the graft is well settled. The knee is then maintained carefully in neutral rotation and between 80-90 degrees of flexion while the graft is then tensioned and fixation of the opposite end is completed. The surgeon must ensure that the anatomic anterior step-off of the tibia has been re-established.

6. Next, the ACL graft is passed, anchored at the femoral end, and then fixed at the tibial end with the knee at or near neutral extension. The ACL can be properly tensioned only after the joint has been “centered” by re-establishment of physiologic PCL stability. If the ACL were tensioned first, avoidance of constraining the knee in a position of posterior tibial subluxation is difficult.

7. Once bi-cruciate ligament stability has been re-established, collateral laxity can be re-evaluated. The surgeon will generally have a realistic expectation of whether collateral ligament repair or reconstruction will be necessary based upon the examination under anesthesia and exploration of the pathology earlier in the case.
Approximately one half of the MCL injuries associated with MLKI will need further repair or reconstruction.\textsuperscript{28,40} Severe valgus injury generally requires that the surgeon address laxity involving the posterior capsule, posterior oblique area of the posteromedial corner, and mid-medial capsular ligaments.\textsuperscript{38,39,88-92} Care must be taken to avoid over-advancement of the posterior oblique ligament, which may result in a flexion contracture. Avulsion of the distal superficial MCL has less healing potential than proximal lesions and may require attachment to the tibia deep to the pes anserinus expansion.\textsuperscript{39,90} Moderate interstitial laxity in the superficial MCL can be treated by recession of the femoral insertion, although severe disruption may require reconstruction utilizing the autogenous semitendinosus or an allograft.\textsuperscript{88,93}

Lateral and posterolateral corner injuries are more complex than those on the medial side, and have generated a great number of opinions as to the timing and technique of surgery.\textsuperscript{34,94-112} To a significant extent, the technique chosen will reflect the specifics of the pathology, as a very wide range of injury pattern exist. However, an accumulating body of evidence suggests that primary reconstruction may not always be enough to ensure long term stability, even if done early, and that primary reconstruction with grafts is frequently necessary to obtain a stable knee.\textsuperscript{45,96,103,107,111} The plethora of technical options for lateral-sided ligament reconstruction reflects the fact that care is still evolving. However, all authors emphasize the importance of an isometric repair and reconstruction.

8. After surgery, the injured knee is immobilized in extension. Cryotherapy may be helpful in the control of post-operative discomfort. An interferential electrical stimulation unit for pain and swelling is also frequently utilized. The cuff and electrode pads are applied in the operating room.

REHABILITATION
The rehabilitation of patients with combined complex knee injuries has paralleled the advances in the surgical techniques of the MLKI. These techniques, which emphasize the anatomical restoration of injured tissue, present the therapy team with an unmatched opportunity for optimal functional rehabilitation. However, no two instances of MLKI are exactly alike. Therefore, rehabilitation programs must be "customized" to the individual patient, and ongoing communication between the surgeon and the rehabilitation team is imperative to assure successful outcomes.

Detailed rehabilitation protocols for patients with MLKI have seldom been published.\textsuperscript{114-115} Furthermore, due to the uniqueness of each MLKI, randomized trials have not been performed. The strategies in the rehabilitation of the patient with MLKI may seem to be diametrically opposed as in the case of protecting both the reconstructed ACL and PCL, thereby creating significant challenges for the clinician. The progression of rehabilitation should occur in a logical sequence and include the following considerations:

1. Protection of ligament grafts and repaired tissues
2. Interventions to decrease pain, reflex inhibition, effusion, and edema
3. Measures to maximize ROM
4. Initiate, facilitate, and enhance neuromuscular control
5. Improve proprioception
6. Enhance dynamic stability of the knee through exercises and functional activities\textsuperscript{114}

SCIENTIFIC BASIS AND BIOMECHANICS OF KNEE REHABILITATION FOR THE PATIENT WITH MLKI
Clinicians should incorporate both open kinetic chain (OKC)\textsuperscript{116-124} and closed kinetic chain (CKC)\textsuperscript{125-132} exercises into the rehabilitation of patients with MLKI. No studies exist that have discussed the specific ligamentous strains with MLKI. Consequently, all studies have researched CKC and OKC forces in isolated ligament injuries; therefore, this information will be applied to the MLKI. Furthermore, co-contraction exercises, particularly for patients with MLKI, may be protective to all the healing structures by stabilizing the knee joint.\textsuperscript{125-127,133,134}

The following is a list of recommended "safe" guidelines regarding isolated ACL and PCL initial OKC and CKC exercises. However, because of the complexity of MLKI, these guidelines will need to be customized based on concomitant injured structures, surgical procedures, and the patient's response to rehabilitation.\textsuperscript{114}

OKC knee extension
- 90-30 degrees for ACL rehabilitation
- 90-0 degrees for PCL rehabilitation

OKC knee flexion
- Full range of motion for ACL rehabilitation
- Contraindicated for PCL rehabilitation, in the early phases

CKC exercises
- 0-60 degrees for ACL and PCL rehabilitation
Phase I (Weeks 1-6): Protective Phase

This early phase of the post-operative course is quite constant, irrespective of the specifics of the pattern of MLKI and the surgical technique employed. The priority is to protect the reconstructed and repaired tissues, while implementing strategies to reduce pain, effusion and edema, regain ROM, and initiate/facilitate muscle function. During this phase of rehabilitation, a long-leg brace is utilized. For the first 4-6 weeks, this brace is locked in extension while maintaining a strict non-weight bearing status. Dependent upon a variety of factors, including patient compliance and the type of reconstruction/repair, partial weight bearing status may be initiated during weeks 4-6. However, controlled non-weight bearing early is encouraged, generally beginning approximately one week after surgery, but with a proximal pad or counterforce support on the proximal tibia to minimize the effects of gravity and to prevent posterior tibial sag.\textsuperscript{135} Arms et al\textsuperscript{135} demonstrated increased strain on the PCL as the knee flexes, with maximum strain recorded at 100 degrees. Therefore, knee flexion past 90 degrees is not allowed during the first 6 weeks of the rehabilitation program.

Facilitate Soft Tissue Healing. A predictable progression of soft-tissue healing response occurs after severe trauma and surgical intervention. The initial phase of acute inflammation is followed within a week by phases that include collagen fibroplasia, maturation, and then remodeling. During the acute inflammatory phase, various physical therapy modalities are effective in decreasing the severity of pain and effusion and, thus, facilitate a healing response. Soft tissue healing is a long process. The first three stages each taking weeks at a time. During soft tissue healing, it is important that the appropriate stresses be imposed on injured tissues to promote physiologic healing responses, minimize negative changes, and facilitate the proliferation and alignment of collagen fibers.\textsuperscript{134}

Decrease Pain and Effusion. Both pain and the presence of an effusion significantly delay ROM gains and quadriceps muscle function. Spencer et al\textsuperscript{136} demonstrated that as little as 20-30 mL of fluid in the knee joint can retard the contraction of the vastus medialis oblique muscle. Various modalities (cryotherapy, interventional electrical stimulation, etc.) may supplement pharmacological therapy in decreasing post-surgical pain, effusion, and edema, and lead to improved neuromuscular control early in the rehabilitation process.

**Restore Full Physiological Extension.** Full physiologic ROM is necessary for normal function of the knee. Prolonged immobilization is associated with many detrimental effects to the joint and surrounding structures, including the development of intra-articular and peri-articular adhesions, arthrofibrosis with loss of joint motion, degradation of hyaline cartilage, and decreased bone mass. The goal is the steady and gradual return of motion.\textsuperscript{134}

Obtaining extension must take precedence during the initial phases of rehabilitation. The goal is to gain at least neutral extension by the end of the second week. This goal will be most difficult when injury patterns involve MCL pathology. Additionally, the repaired or reconstructed PCL comes under increasing stress as the knee goes into hyperextension. The PCL/posterior lateral corner combination injuries are especially vulnerable, as the lateral structures also come under increasing tension with terminal extension secondary to the "screw-home" phenomena.\textsuperscript{134} To quantitatively document the ROM, a measurement of knee extension via heel height difference is taken, where 1 centimeter in heel height is equal to approximately 1 degree.\textsuperscript{137,138}

Oftentimes, additional treatment interventions need to be performed to achieve full ROM. For patients with hypomobilities, utilization of the total end range time (TERT) stretching formula is instituted. The TERT formula is used to create plastic deformation of the non-contractile tissue.\textsuperscript{139-140} This formula is based on the product of intensity, duration, and frequency. The intensity is the maximal stretch intensity the patient can tolerate based on comfort.\textsuperscript{140}

**Active warm-up.** In the early stages of rehabilitation this is modified based on soft tissue healing constraints (active assistive range of motion (AROM), short arc exercises, etc).

**Heat in a stretched position.** The first TERT is applied.

**Mobilization/ROM.** Hypomobility of patella-femoral cephalic glide interferes with the normal function of the extensor mechanism which may lead to loss of active and passive ROM or a quadriceps muscle lag. Patella-femoral caudal glides are utilized to increase knee flexion. In the single cruciate ligament reconstruction surgeries, mobilization of the tibio-femoral articulation is rarely necessary for patients who have had MKLI surgeries.\textsuperscript{134}
Static stretching or proprioceptive neuromuscular facilitation (PNF) contract-relax. Oftentimes, the musculo-tendinous unit also adaptively shortens which also leads to flexibility deficits. The static portion of the stretches should be held for 30 seconds for younger patients. However, if the patient is older than 60, greater benefits are obtained maintaining the stretch position for 60 seconds. Moreover, PNF techniques, such as contract-relax/hold-relax, can be included as part of the treatment program.

**Therapeutic exercise.** Passive range of motion (PROM) can only be utilized and maintained if adequate neuromuscular control exists.

**Total leg strengthening (TLS).** Dynamic stabilization exercises for the entire lower extremity should be performed, which also includes core stability exercises.

**Ice in a stretched position.** The second TERT is applied at the completion of the physical therapy treatment session.

**Home exercise program (HEP).** The patient will perform a third TERT.

**Initiate Neuromuscular Control to Prevent Reflex Inhibition.** Quadriceps muscle weakness and atrophy in the initial stages post-operatively is unavoidable, but must be addressed immediately in order for the patient to meet their rehabilitation goals. Isometric quadriceps sets are initiated post-operatively day one, with a progression to a straight leg raise without the brace once adequate neuromuscular control is obtained. As previously discussed, various modalities are utilized to decrease the post-operative pain and effusion which are inevitable in all patients with MLKI. Quadriceps muscle sets can be supplemented with electrical stimulation to augment strength. Additionally, the use of biofeedback may be particularly useful in this population.

**Enhance Neuromuscular Proactive Control and Stability: Exercise Progression Continuum.** Exercise progression forms the foundation of the exercise program. The continuum stages are as follows:

- Sub-maximal intensity pain-free multiple angle isometrics
- Maximal intensity multiple angle isometrics
- Sub-maximal intensity short arc exercises
- Maximal intensity short arc exercises
- Full ROM sub-maximal intensity exercises
- Full ROM maximal intensity exercises
- Plyometric exercises
- Functional specificity exercises

During Phase I, the emphasis is on the first three stages of this exercise progression. Total leg strength can also be performed, but caution must be taken when using the entire lower extremity and long lever arms, since total leg strength may put stresses on the healing ligaments.

**Improve Proprioception/Kinesthesia.** Knee proprioception and kinesthesia are disrupted by injury. Mechanoreceptors within the cruciate ligaments are injured during the ligament failure of MLKI and do not regenerate into the reconstructed grafts. In addition, receptors within the collateral ligaments and capsule are damaged to varying degrees. Specific exercises that are safe for the healing structures early in the rehabilitation program may facilitate the remaining intact mechanoreceptors to compensate for those that are absent. Various exercises that may be used at this time include angular joint replication training, end ROM reproduction training, and perturbation training.

**Phase II (6-12 Weeks): Guarded Protection**

In Phase II, continued protection of repaired and reconstructed tissue is necessary, although progressive guarded stresses are imposed as the rehabilitation program continues. The patient may generally be allowed full weight-bearing in their post-surgical brace at the beginning of the sixth week. Patients must have at least active neutral extension and no evidence of a quad lag to assume full weight bearing. A normal gait pattern is necessary to dispense with crutches. The long-leg post-operative brace is discontinued when the patient begins to ambulate without crutches at approximately 6-8 weeks.

A functional brace is worn for all activities of daily living until approximately 12 weeks post-operative. It is highly recommended that patients who plan to return to athletic activity or manual labor utilize the brace for those specific activities for at least 18 months after surgery. At the present time, no published studies exist that assess the efficacy of functional bracs after MLKI. Nevertheless, it appears to be important to provide the patient with external support because muscle function and proprioception are deficient during the early stages of recovery from these devastating injuries.

**Restore Full Physiological ROM.** Neutral extension should have been obtained by the end of the sixth week. The goal of the second phase of rehabilitation is to achieve physiological knee extension of the involved extremity equal to the uninvolved. Application of the TERT formula is continued if needed. Ideally, flexion
should gradually increase until ROM is symmetrical to the uninvolved side by weeks 8-12. However, consistently obtaining full flexion may be difficult. If neutral extension and flexion to 125 degrees have not been obtained by week 12 and gains in ROM have plateaued, surgical intervention in selective patients with MLKI is considered.

**Improve Proprioceptive/Kinesthesia.** Proprioceptive/kinesthesia exercises are advanced in a systematic fashion. Unlike isolate ligamentous injuries, the rate of progression for these exercises varies considerably between patients with MLKI. Suggested progression is as follows:

- Partial weight bearing (PWB) - Full weight bearing (FWB)
- Double-leg exercises - Single-leg exercises
- Single plane tilt board - Multiple plane tilt board
- Eyes open - Eyes closed
- Perturbation training (proactive)

**Increase Muscular Strength, Power, and Endurance.**

An important part of the rehabilitation program for the patient with a MKLI is dynamic stability, which helps protect the knee joint and compensates for any residual impairments. Core stability training can also be included for a comprehensive rehabilitation program. As previously described, the exercise progression forms the foundation of the exercise program. In Phase II, the emphasis to enhance neuromuscular dynamic stability is on stages 3-6 of the exercise progression continuum.114

After knee surgery, patients have a tendency to unload their surgical extremity. Neitzel et al155 have demonstrated that patients continued to unload the surgical limb for at least six months, and then normalized their weight bearing by one year. Based on these findings, patients are encouraged to begin single leg exercises earlier in the rehabilitation program.

**Phase III (12-24 Weeks): Improve Proprioception/Kinesthesia**

Exercises from phase II are continued with the addition of more aggressive progressions such as perturbation training exercises. These exercises are progressed from submaximal to maximal, slow to fast, and known (proactive) to unknown (reactive) patterns. At approximately week 24, low intensity agility drills may be initiated. Exercises such as controlled acceleration and deceleration, slideboard, and jumping rope form the foundation of these exercises.114, 129

**Increase Muscular Strength, Power, and Endurance.** In the later phases of rehabilitation, the resistive exercises for both CKC and OKC exercises use the principles of progression and overload.156-158 The OKC limitations are as follows:114

- **Weeks 12-18**
  - 30-90 degrees for resisted knee extension exercises (at about week 12-depending on joint stability, patello-femoral joint chondrosis, surgical repairs, co-morbidities, and doctor approval)
  - Resisted knee flexion exercises are contraindicated at this time secondary to the stress placed on the PCL

- **Weeks 18-24**
  - 0-90 degrees for resisted knee extension exercises (at about week 18-depending on joint stability, surgical repairs, patello-femoral joint chondrosis, co-morbidities, and doctor approval)
  - 90 degrees for resisted knee flexion exercises (at about week 18-depending on joint stability, surgical repairs, co-morbidities, and doctor approval)

A combination of concentric and eccentric exercises should be included in the rehabilitation because most functional activities use both modes of muscle actions. To improve muscular power, the patient exercises at fast speeds with maximum effort activities. Progression may include faster speed isokinetic training and functional training activities using more dynamic exercises, such as low intensity plyometric exercises.114

**Enhance Neuromuscular Reactive Stability.** Neuromuscular reactive training is important to provide dynamic stability of the knee. Development of normal functional patterns is one of the goals of the training program. During this phase, the primary motor learning responses re-develop and activities progress from a conscious to an unconscious level where the responses occur automatically. Primary muscles involved in the compensatory patterns (quadriceps, hamstrings, and gastrocnemius muscles) following ACL injuries are important in helping the patient return to various activities.159-163 Therefore, a patient with a MKLI may also need to rely on some of these compensatory patterns to create the dynamic stability for the knee. However, because of the complexity of the MKLI, differences exist in the way the patients are going to compensate to provide dynamic knee stability. Consequently, as previously discussed, the rehabilitation program needs to be customized to each individual patient.114
Phase IV (> 24 Weeks): Functional Specificity and Return to Activities

A functional testing algorithm (FTA) is used to evaluate and progress a patient through the rehabilitation program. This phase focuses on the last few stages of the exercise progression continuum. The details and specific criteria are described by Davies and Zillmer.114 The FTA progresses the athlete through a series of stages, with each one becoming progressively more difficult. The patient must pass through each stage in a systematic process in order to progress to higher levels of functional activities. If the patient fails a test of the FTA, the rehabilitation program is then focused upon that area until the deficit is adequately addressed.114

SUMMARY

No randomized controlled trial studies exist regarding the optimum surgical and rehabilitation guidelines for a patient following MLKI. Furthermore, these studies would be difficult considering the complexity and uniqueness of each MLKI. Both surgery and rehabilitation are customized to meet the particular need of each patient with a MLKI. Guidelines regarding mechanisms and classifications of injuries, surgical procedures, and limited evidence-based literature on rehabilitation combined with our empirically based experience with patients with MLKI have been presented.

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ABSTRACT

Non-operative and operative complications are common following multiple ligament knee injuries. This article will describe common complications seen by the surgeon and physical therapist following this complex injury. Complications include fractures, infections, vascular and neurologic complications following injury and surgery, compartment syndrome, complex regional pain syndrome, deep venous thrombosis, loss of motion and persistent laxity issues. A brief description of these complications and methods for evaluation and treatment will be described.

**Key words:** complications; knee dislocation; vascular; neurologic

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INTRODUCTION
Multiple ligament knee injuries (MLKI) are usually the result of knee dislocations following either high energy motor vehicle accidents or low velocity sport injuries. Significant morbidity is associated with knee dislocation including multiple ligament disruption and neurovascular damage. The treatment of the MLKI can be very involved. Therefore, the possibility of complications is extremely high. Complication rates are much higher than with standard single-ligament knee injuries. In this article, complications are divided into non-operative and operative and are discussed separately.

NON-OPERATIVE COMPLICATIONS
OPEN DISLOCATIONS
Open dislocations of the knee represent approximately 20-30% of all dislocations. These injuries are serious and are due to high energy trauma, often accompanied by vascular and neurologic injury. Usually, significant soft tissue injury occurs that must be addressed before any reconstructive procedure is initiated. These other injuries are what ultimately determine the success of any reconstructive effort. Significant risk exists for infection and a higher incidence of above knee amputation in this group. Often, the definitive surgical procedure is delayed to allow for eradication of infection and soft tissue healing. Due to the severity of this injury functional expectations following salvage of the limb need to be guarded and realistic goals set.

Associated Fractures
Fracture dislocations are believed to occur in 10-20% of all knee dislocations. Most commonly, the fractures include avulsion fractures of the fibular head, tibial spine fractures, and Segund’s fractures which is an avulsion fracture of the lateral tibial condyle. Although these are technically fractures, they represent ligament avulsions and are treated by repairing/reconstructing the appropriate ligament. However, tibial plateau fractures are more serious and can compromise the overall success of any surgical procedure. Moore classified five types of plateau fractures associated with dislocations. The higher the type, the more serious the fracture. Plateau fractures add an additional dimension to the surgical planning as stable fracture fixation must be achieved along with addressing the ligamentous instability. Due to the fact that plateau fractures involve the articular surface, a greater risk of developing post traumatic osteoarthritis exists and, therefore, the overall functional outcome, because of pain and stiffness, may be compromised.

Vascular Injury
Popliteal vessels have limited mobility and can be injured during knee dislocations. Vascular injury is associated with knee dislocation in 30% to 35% of cases (Figure 1 and 2). Popliteal vessels can be injured by stretching in anterior dislocations and by direct trauma during posterior dislocations. Injury can be limited to intimal flap (one in which the inner lining, the intima, of the blood vessel is torn while the remaining layers remain intact), or complete vessel rupture (Figure 3 and 4). The vascular status of a grossly unstable knee should be evaluated immediately by palpation of dorsalis pedis and posterior tibial pulses. Collateral circulation is inadequate to provide distal flow in case of injury to popliteal artery. Absence of pulse mandates an arteriogram to assess vascular integrity.

Neurologic Injuries
Tibial and, more commonly, peroneal nerves can be injured during a knee dislocation. Peroneal nerve injury is reported to occur in 14% to 35% of knee dislocations, especially posterolateral dislocations. Traction of the peroneal nerve is the most common mechanism of injury. The severity of the nerve injury can vary from neuroapraxia to complete disruption. Prognosis varies but is generally poor with no recovery in more that 50% of cases. Peroneal nerve injury clinically manifests as foot drop which may be treated with an ankle-foot orthoses (AFO). Ischemia, induced by vascular injury or compartment syndrome, could also cause neurologic injury.

OPERATIVE COMPLICATIONS
Operative complications of multiple ligamentous reconstruction includes morbidity associated with iatrogenic
vascular and nerve injury, anesthesia, compartment syndrome, tourniquet and wound complications, deep venous thrombosis, and failure of the repair.

Iatrogenic Vascular Injury

Previous vascular repair could be compromised or disrupted by direct trauma during surgical reconstruction of the ligaments. Intimal flaps undiagnosed by angiography could also occlude during surgery and compromise the extremity circulation (Figure 5). Pre-operative, intra-operative, and post-operative vascular evaluation is important with or without vascular repair. Avoidance of using a tourniquet is recommended after vascular repair. If a tourniquet is used, application should be distant from the vascular repair and the time should be minimized.

Iatrogenic Nerve Injury

Nerve injury during multiple ligament reconstruction usually is incisional and involves sensory branches. The infrapatellar and sartorial branches of the saphenous nerve on the medial side of the knee are the most affected nerves. Hypersensitivity and dyesthesias are the most common complaints. Complex regional pain syndrome discussed later in this article could also be caused by cutaneous nerve injury. The peroneal nerve, which lies close to the fibular head could be injured during lateral exposures.

Compartment Syndrome

Compartment syndrome can occur after arthroscopic knee surgery due to extravasation of arthroscopic fluid. Patients with MLKI after dislocations have capsular and fascial defects. Extravasation is a leakage of arthroscopic fluid between fascial planes that can be a potential cause of compartment syndrome. Capsular sealing usually occurs in 10-14 days and delaying surgical reconstruction may decrease the risk of this complication. Compartment syndrome could also be induced by ischemia due to vascular injury or re-perfusion after vascular repair.

Tourniquet Complications

Tourniquet complications are believed to be time-dependent and related to duration of compression. Age of the patient, excessive pressure, local anatomy, and insufficient pressure are also other contributing factors. Patients with MLKI after knee dislocation may have non-occlusive vascular injury. Tourniquet induced stasis might lead to formation of an arterial thrombus in these patients which may cause limb ischemia and subsequent amputation. Use of a properly functioning tourniquet, accurate application, limb exsanguination (the process by which blood is removed from the leg by elevation or use of a compressive device or elastic wrap before tourniquet application), checking the pressure level during surgery, and reducing tourniquet time are believed to decrease complications associated with tourniquet application.

Wound Problems

Superficial or deep wound infections may happen after ligamentous knee surgery with an incidence of 0.30 to 12.5% in open reconstructions. Patient’s age, general health, skin condition, steroid use, prolonged tourniquet time, and prior knee operation are all contributing factors. Prophylactic antibiotic therapy before and after knee reconstruction for 24 hours (or until drain removal) is recommended and is shown to decrease the risk of wound infections. Additionally, excessive traction can cause blistering during wound closure (Figure 6).

Complex Regional Pain Syndrome

Complex regional pain syndrome, also known as reflex sympathetic dystrophy, can occur after knee surgery and is characterized by pain with the intensity out of proportion to the severity of injury, prolonged functional recovery, vasomotor imbalances, edema, and atrophy. Hypersensitivity to painful stimuli, atrophy, stiffness, hypervascularity, and osteopenia are the common clinical findings in the affected patients. The severe pain can lead to muscle inhibition and soft tissue contractures of the knee and cause...
slow progression and painful physical therapy. Early recognition is important to prevent frustrating complications. Steroids and non-steroidal anti-inflammatory drugs, as well as sympathetic blocks, have been shown to have some benefit.21,31,32

Deep Vein Thrombosis
An unusual complication following any knee surgery or period of prolonged immobilization is a deep venous thrombosis (DVT).33 Conditions such as trauma, surgery, or prolonged immobilization may impair venous return, leading to endothelial injury and excessive clotting of blood in the lower extremity. Deep venous thrombosis can be classified as either proximal or distal depending on the site of formation either proximal or distal to the trifurcation of the popliteal vein. Because the proximal versions are larger than the distal, the proximal DVT are thought to be more likely to end up as a pulmonary embolism.34,35 A pulmonary embolism occurs when a dislodged fragment of the blood clot travels to the lungs where it can block one of the pulmonary arteries or one of its branches. This blockage in the lung is an obvious medical emergency as it can be life threatening.

Due to decreased hospital stays, undiagnosed or silent DVT and pulmonary embolisms may be seen by physical therapists. Physical therapists routinely see patients following outpatient surgical procedures such as reconstruction for MLKI’s. Common signs and symptoms of a DVT include calf pain, swelling, discoloration of the affected area, and warmth to palpation of the surrounding skin. The major problem with diagnosing this potentially life threatening condition is that the same identical symptoms occur after most lower extremity surgical procedures. Additionally, it must be understood that some DVT produce minimal symptoms and can present completely “silent.”

One of the more common physical examination tests used by physical therapists to diagnosis a DVT is the Homans’ sign. Homans’ sign is tested by passively dorsiflexing the patient’s foot with the knee fully extended. Pain in the calf indicates a positive sign for DVT.36 Tenderness can also be found with palpation of the posterior calf. Unfortunately, previous reports suggest that the Homans’ sign has essentially no diagnostic value.37,38

Fortunately, clinical decision rules have been developed to assist in the diagnosis of DVT. A clinical decision rule is described as a way to quantify individual contributions of components of the medical history and physical examination to make a correct diagnosis.39 Wells and colleagues40-42 have used a series of studies to determine that patients can be placed in categories dependent on their clinical decision rule scores. Their clinical decision rule is based on nine medical history items and physical findings (Table 1). Patient’s scores and their proposed probability of DVT are listed in Table 2.

![Figure 6. Skin blisters from excessive traction during wound closure. (Reprinted with permission from Hegyes MK, Richardson MW, Miller MD. Knee dislocation: Complications of nonoperative and operative management. Clin Sports Med. 19:533, 2000)](image-url)
Loss of Motion

Loss of knee motion may occur after any injury to the knee and is the most common long-term complication following MLKI. Multiple reasons exist for knee stiffness following this injury. Soft tissues injury, hemarthrosis with secondary adhesions, excessive scarring due to immobilization, joint or muscle contractures, complex regional pain syndrome, quadriceps scarring, notch scarring, infection, delayed or rushed surgical procedures, excessive graft tension, malpositioned graft, and graft choice all can cause limitations of motion. To combat motion loss several applications are typically applied to the patient post-surgery as described by Irrgang and Fitzgerald.

Reconstruction of anterior cruciate ligament is more associated with loss of extension versus posterior cruciate ligament reconstruction which is associated more with lack of flexion. Medial collateral ligament reconstruction involves flexion and extension equally and has the highest rate of motion loss after surgery. Lateral collateral ligament repair is not believed to have a significant impact on postoperative range of motion. Intercondylar notch scarring and capsulitis are the most common causes of knee stiffness after ligament reconstruction. Intercondylar notch scarring is caused by scar formation in the notch which can block extension.

To protect the healing of replaced ligaments, the patient is placed in a postoperative brace locked in full extension for the first 4-6 weeks. Emphasis is placed on gaining equal full terminal extension, except in cases of those with posterolateral corner reconstruction. With a posterolateral reconstruction emphasis of passive knee extension is to 0 degrees and not equal terminal extension bilaterally. Passive knee flexion is limited to less than 90 degrees during the first 6 weeks. Passive flexion is performed cautiously with a hand placement that will decrease the amount of posterior translation of the tibia (“drop-back”) during knee flexion range of motion (Figure 7). Active knee flexion via hamstring muscle contraction is avoided for 6 weeks to prevent posterior tibial translation which could be detrimental to the posterior cruciate reconstruction. Depending on ligament damage, a slight varus or valgus force may be applied during knee flexion and extension exercises to take additional stress off of the healing medial collateral or lateral collateral ligaments, respectively (Figures 8 and 9). If extension motion is lost, treatment is physical therapy and possible use of extension dropout cast to maintain extension.

Capsulitis results from inflammation in the periarticular tissue. Diffuse pain, tenderness, effusion, weakness of extensor mechanism, and flexion contracture are common problems which can result in a flexed knee during gait. Early recognition can prevent further loss of motion. Early treatment includes the use of nonsteroidal anti-inflammatory drugs with non-aggressive physical therapy. Additionally, patellofemoral mobilization is performed for medial/lateral and superior/inferior glides to ensure adequate mobility for full functional return of the quadriceps mechanism (Figures 10 and 11). In most cases, the decision can be made by three months that surgical intervention is indicated. Surgical intervention usually includes lysis of adhesions and a lateral release to restore patellar motion. Physical therapy emphasizing improvement of extension is started after surgery. Severe cases might require arthroscopy, quadricepsplasty, and salvage procedures such as patellectomy and total knee replacement.

Persistent Laxity

Knee instability is not as common as stiffness after multiple ligamentous reconstruction and can be caused by failure to
recognize associated injuries, non-isometric ligament reconstruction, and graft failures. Posterior sag is the most common form of persistent laxity which can happen after posterior cruciate ligament reconstruction due to failure to address posteromedial or posterolateral injuries, improper graft tensioning or placement, graft weakness, and early open chained hamstring muscles exercise. Failure to recognize associated ligament injuries is believed to be the most common cause of suboptimal outcomes after combined anterior and posterior cruciate ligament surgery. Complete history and physical exam including magnetic resonance imaging (MRI), examination under anesthesia, and arthroscopy for diagnostic purpose in selected cases can help identify the correct pathology. Post-operative physical therapy can affect the outcome of posterior cruciate ligament reconstruction leading to posterior sag and persistent laxity. Open chain hamstring muscles exercise and weight bearing in flexion in the early post-operative period can increase forces in the posterior cruciate ligament and cause laxity with posterior sag.

Miscellaneous Complications
Medial femoral condyle osteonecrosis has been reported as one of the complications of the posterior cruciate ligament repair. The cause is believed to be increased pressure causing vascular insufficiency in the bone. Medial knee pain with tenderness on the medial femoral condyle are the most common signs and symptoms. Anterior knee pain can be seen after posterior cruciate ligament reconstructions with posterior sag due to increase patellofemoral forces that lead to early patellofemoral osteoarthritis. Pain in the graft harvest site, synovitis, and prominent hardware are other causes of anterior knee pain after ligament reconstruction.

Summary
Significant morbidity is frequently associated with MLKI before and after operative intervention. Early diagnosis of these complications can play a significant role in improving outcome.

REFERENCES


ABSTRACT

Stability at the knee joint is provided by both the static structures, including the ligaments and joint capsule and the coordinated activation of dynamic structures surrounding the joint. These dual stabilizers allow for functional movements, such as gait, to occur safely, effectively, and efficiently. In the presence of a multi-ligament knee injury (MLKI) an absence of static stability can result in an increased reliance on the dynamic knee stabilizers. If sufficient stability is not provided, the potential for an increase in abnormal movements in the knee joint can result. These potential gait alterations that may be associated with a MLKI can result in abnormally high stresses on healing tissues and potentially high shearing forces on articular cartilage, resulting in early breakdown. Early recognition of gait abnormalities and an appropriate implementation of a gait re-training program to control abnormal forces in a patient following an MLKI or a surgical intervention for a MLKI are critical for successful long-term outcomes.

Key words: Gait, knee, biomechanics, multi-ligament knee injury
INTRODUCTION
The knee joint, comprised of the tibiofemoral and patellofemoral joints, is a complex and dynamic structure and functions as the mobile point of the two longest levers in the body. Therefore, the neuromuscular components of the knee must control large magnitude torques imposed by the environment in order to provide adequate stability of a highly mobile joint. The required stability is created in the joint from both static and dynamic stabilizers. Passive stability is created from the ligamentous and capsular structures surrounding the knee. Dynamic stability is provided by the muscular contractions occurring around the joint during movement. Compromise of either the static or dynamic stabilizers of the knee will likely result in impaired movement, functional deficits, and potentially both short and long-term disability.

Walking (gait) is a functional movement that requires effective and efficient knee joint stability via both passive and dynamic joint restraints. Injury to any of the static stabilizers of the knee places an increased burden on the remaining ligamentous structures to provide stability during functional activities such as walking. In the case of a multi-ligament knee injury (MLKI), increased joint laxity in the absence of effective static ligamentous restraints can result in excessive demands on the dynamic stabilizers of the knee and lead to excessive or abnormal motion in the knee joint. These altered movement patterns can increase tensile stress on healing tissues and ultimately deter healing in the patient, both post-injury and post-surgically. In addition, this altered repetitive abnormal movement may place abnormally high stress on the articular cartilage of the knee, which could result in premature breakdown of the cartilaginous tissues. Hence, the physical therapist’s ability to recognize and correct altered gait in a patient following a MLKI is critical to ensure that the knee joint is not subjected to altered movement patterns and abnormally high forces to the joint.

BIOMECHANICS OF THE KNEE
A discussion of the implications of normal and pathologic gait on the knee joint should begin with an understanding of the role of the static stabilizers of the knee. Static stability in the knee is provided by the four primary ligaments of the knee: anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL), and the lateral collateral ligament (LCL). Understanding each ligament’s individual contribution to the stability of the knee joint in both unloaded and loaded positions will help the clinician better appreciate their role in normal gait, and how gait will potentially be altered in the absence of one or more of these ligaments in the case of a patient with MLKI.

The cruciate ligaments are the primary static restraints to anterior and posterior translation of the knee joint. The medial and lateral collateral ligaments provide frontal plane stability to the knee, as they are the normal primary static restraints to valgus and varus movement at the joint, respectively. During a normal gait cycle, these ligaments will control frontal plane forces imposed on the knee. The amount of ligamentous stability provided by each of these ligaments is defined by three underlying properties. These properties include the attachment location of the ligament, the “just taut” length of the ligament, and the stiffness properties of the ligament. The anatomic location of the ligament attachment on the tibia and femur create the functional length of the ligament and help to determine their primary restraint function. Slight anatomic variations in the location of the ligament attachment can potentially alter the laxity of the knee joint in multiple planes. The “just taut” length of the ligament dictates the maximum amount of translation or motion in the joint prior to the ligament beginning to resist movement in that plane. Finally, the stiffness of the ligament will dictate how much motion is available after the ligament reaches its slackening end point and is stressed beyond that limit, the “just taut” length, but prior to failure.

The knee can be biomechanically described as having three axes of rotation and six degrees of freedom. Along each axis and plane, the knee possesses the ability to rotate and translate, respectively, which allows for a total of twelve motions. About the X-axis and in the sagittal plane, the knee has the ability to rotate into flexion and extension and translate in an anterior and posterior direction. About the Y-axis and in the frontal plane, the knee has the ability to rotate into abduction and adduction and translate in a medial and lateral direction. Finally, about the Z-axis and in the transverse plane, the knee has the ability to rotate into internal and external rotation and translate into distraction and compression. Each of these six motions is needed to execute a normal gait cycle. Compromise or limitations created by MLKI can result in stereotypically altered gait patterns.

NORMAL GAIT
Prior to discussion of abnormal gait mechanics caused by MLKI, an understanding of normal gait mechanics is essential for the determination and differentiation of
abnormal from normal gait mechanics. The walking gait cycle can be sub-divided into distinct events that together describe the normal cycle of gait. Typically, a gait cycle is described as beginning at initial contact on one foot and ending when that foot completes a full stride and immediately prior to the next initial contact. Each gait cycle can be sub-divided into eight categories. The first five components of the gait cycle include initial contact, loading response, mid-stance, terminal stance, and pre-swing. Together these components make up the stance phase of gait, which comprises approximately 60% of a gait cycle. The remaining 40% of the gait cycle makes up the swing phase of gait and it includes subdivisions of initial swing, mid swing, and terminal swing. During each phase of gait, contributions from all three planes of movement result in a normal gait pattern.

Sagittal Plane Kinematics in Gait

The greatest amount of angular motion at the knee occurs in the sagittal plane during normal gait. The knee typically begins in a near fully extended position at initial contact and then progresses through a biphasic pattern of sagittal plane motion. (Figure 1) As the knee progresses from initial contact to loading response, it flexes to approximately 20 degrees of flexion. (Figure 2) This represents the peak knee flexion angle during the stance phase of gait. The knee then begins to extend during mid stance to a near fully extended position. Following this period of extension, the knee begins to flex during the pre-swing phase in preparation for swing phase, at which time adequate knee flexion is needed to allow toe clearance. Most authors agree that between 60 degrees and 70 degrees of knee flexion is needed to successfully accomplish the swing phase of gait.

Sagittal Plane Kinetics in Gait

Muscular contributions to a normal gait pattern in a sagittal plane are determined by the external knee flexion-extension moment at the knee. The external moment is the rotational force (or torque) that is imposed on a joint by the environment during closed-chain activity. The magnitude and direction of this force is determined by the location of the vertical ground reaction force in relation to the axis of rotation of the joint in question. In response to this externally imposed force, the body responds with an equal and opposite internally generated moment to counteract this external moment and allow maintenance of an upright position and progression through the normal gait cycle. This internal moment is typically generated through the coordinated recruitment of the musculature surrounding the joint.

In the sagittal plane, a biphasic pattern of kinematic activity is also observed. As an individual initiates a gait cycle and begins the initial contact phase, the vertical ground reaction force is typically anterior to the knee, creating an external extension moment at the joint. This torque is counterbalanced by a brief, initial activation of the hamstrings and gastrocnemius musculature. As the knee begins to flex and proceed into loading response, the vertical ground reaction force moves posterior to the knee joint axis, which generates an external knee flexion moment. (Figure 2) In order to develop this equal balance of moments, the body generates an internal extension moment through an eccentric activation of the quadriceps musculature to control knee flexion and limit the flexion excursion to 20 degrees.

As the body progresses to midstance and the knee begins to extend again, the vertical ground reaction force begins to approach the knee joint center. During this phase, knee extension motion is achieved.
through the contribution of several muscles. The quadriceps continue to assist with knee extension initially, however, as midstance progresses the contribution of the quadriceps musculature decreases. At this time, extension is accomplished through femoral advancement over a stabilized tibia, which is driven by the momentum of the body generated by the swing limb. The tibia is stabilized through muscle activation of the soleus muscle at the same time. As a result of this knee extension mechanism driven by momentum generated from the body, the quadriceps muscle activity in the stance limb ceases at the end portion of midstance. From this point forward, the lower extremity progresses through terminal stance and pre-swing. At this time, the lower extremity is primarily preparing for swing phase, and few gait deviations related to multi-ligament knee injuries are expected to be observed.

**Frontal Plane Kinematics and Kinetics in Gait**
The normal knee experiences only between 8 degrees and 12 degrees of motion in the coronal plane during a gait cycle. This motion is primarily utilized to maintain balance over the stance limb during gait. The knee's peak abduction (valgus) angle occurs during the progression of initial contact to loading response. Conversely, peak knee adduction (varus) motion is achieved during the swing phase of gait. Muscular stability is provided in the coronal plane by muscles oriented in both the frontal and sagittal plane. A contribution to frontal plane stability is generated directly by the iliotibial band (ITB), in addition to contributions from the long head of the biceps femoris and upper gluteus maximus muscles, which serve to increase tension in the ITB. Despite their alignment in the sagittal plane, frontal plane joint stability can be generated through co-contraction of the quadriceps and hamstrings musculature. Lloyd et al. noted that 80% of medial lateral stability in the knee is generated through this co-contraction of the quadriceps and hamstrings musculature during dynamic tasks.

**Transverse Plane Kinematics in Gait**
Similar to the frontal plane, the quantity of rotational motion during gait is smaller than that observed in the sagittal plane. Typically, the knee experiences between 8 degrees and 13 degrees of motion during a typical gait cycle. At initial contact, the femur is externally rotated on an internally rotated tibia. As the knee progresses from initial contact to loading response, the tibia continues to progress to its position of maximum internal rotation at the end of loading response. The dynamic control of this motion is minimal. The majority of transverse stability at the knee is provided by static structures surrounding the knee. This lack of dynamic stability makes injury to the static stabilizers more debilitating during gait as there is a lack of dynamic support to compensate for a lack of static stability. The body's limited dynamic stability to resist the internal tibial rotation occurring at loading response is provided by the tensor fascia lata and the biceps femoris muscle.

**PATHOLOGIC GAIT AS A RESULT OF A MLKI:**

**SAGITTAL PLANE**
Abnormal gait patterns can occur in all three planes as a result of injury to the static stabilizers in the knee. Injury to one or more of the surrounding knee ligaments can result in excessive demands on the dynamic knee stabilizers. If the dynamic stabilizers are insufficient to compensate for the lack of static stability, abnormal gait motion and moments can result. The most common gait abnormalities discussed in the literature are in the sagittal plane in a patient with an ACL deficient knee.

Bercuch et al. first discussed a typical ACL deficient knee gait pattern in 1990, which they termed a “quadriceps avoidance pattern.” In their study of 16 ACL deficient subjects, these authors noted that 75% of the participants presented with a reduction in internal knee extensor moment. This was interpreted by the authors as an absence of quadriceps femoris activation. Essentially, the authors noted a failure of the subjects’ knees to progress through the normal biphasic pattern of sagittal plane flexion and extension moments and rather, remained in a stable position, without quadriceps muscle activation through stance phase until pre-swing, when the subjects began to flex their knee in preparation for swing (Figure 3 and 4). The theorized mechanism behind this gait pattern was that insufficient quadriceps muscle strength resulted in the subjects’ inability to control the eccentric quadriceps muscle contraction necessary during loading response of gait with a compensatory increase in hamstring muscle activation to control anterior shear during functional movements. Hence, in the absence of the dynamic stability of quadriceps muscle, the knee would “rest on the ligaments” and rely on the static capsular and ligamentous structures of the knee to provide passive, rather than dynamic, support.

Other reports have noted quadriceps reduction, or a decrease of the external flexion (quadriceps muscle bal-
anced) moment, rather than full quadriceps muscle avoidance or total absence of the external flexion moment. For example, using a similar experimental design to the study by Berchuk et al., Roberts et al. attempted to determine if the quadriceps muscle avoidance pattern was as prevalent as first described in a population that was ACL deficient. A video based motion analysis with electromyography (EMG) on a cohort of 18 ACL deficient patients found that quadriceps muscle activity was present during most of stance phase. This finding was counter to the finding of the absence of the external flexion moment by Berchuk et al., inferring no quadriceps muscle activity during this phase of gait. In addition, Roberts et al. noted that all of the subjects that they studied exhibited the presence of an internal knee extension moment, though this moment was reduced, compared to normal subjects. Hence, the quadriceps muscle avoidance gait pattern was reported to be less common in patients with ACL deficiency than previously described. Roberts et al. were not alone in their findings. More recently, Torry et al. and Ferber et al. also analyzed the gait of those with ACL deficiency and noted a significantly less frequent prevalence of quadriceps avoidance gait than was first proposed by Berchuck et al.

Rudolph et al. proposed an alternate mechanism for the reduction in internal knee extensor moment that Berchuck et al. reported during the stance phase of gait following ACL injury. These authors compared the gait of a cohort of patients with ACL deficiencies who were able to participate in cutting and pivoting activities (labeled copers) to a cohort of patients with ACL deficiencies who were unable to participate in activities of daily living without instability (labeled non-copers). Similar to Roberts et al., Torry et al., and Ferber et al., these authors noted that both copers and non-copers demonstrated significant levels of quadriceps femoris muscle activity, further substantiating the theory that quadriceps muscle avoidance gait in patients with ACL deficient knees was less prevalent, and quadriceps muscle reduction more likely, than initially described. Rudolph et al. went on to suggest that the less functional cohort of patients (non-copers) were more likely to demonstrate quadriceps femoris and hamstrings muscles co-contraction during loading response and stance as a means to stabilize the knee joint. These patients presented with a decreased internal knee extensor moment. Contrary to the interpretation by Berchuck et al., the reduced knee extensor moment was an indication of little or no quadriceps femoris muscle activation, Rudolph et al. demonstrated that this moment reduction was more likely a sign of relatively less quadriceps muscle activity compared to hamstrings muscle activity. The relative hamstring muscle activity may be increased as a means to stabilize the ACL deficient knee, rather than the suggestion by Berchuck et al. of the absence of quadriceps femoris muscle activity. Therefore, in the presence of ACL deficiency, patients appear to present with one of several abnormal gait patterns, ranging from a potential complete absence of quadriceps muscle moment, to a reduction in quadriceps muscle activity, to a relative reduction in quadriceps muscle activity in relation to increased hamstring muscle activation as a co-contraction knee stabilization mechanism in these patients.

In the absence of the ACL in the knee joint during gait, the patient may become dependent on the dynamic stabilizers as well as the secondary static stabilizers. Several authors have noted that the MCL becomes the primary restraint to anterior tibial translation during gait and functional tasks in the absence of the...
Hence, following an ACL/MCL injury, the static stability of the knee is significantly decreased, the knee joint may become primarily reliant on the dynamic stability provided by the surrounding musculature.

**PATHOLOGIC GAIT AS A RESULT OF A MLKI: FRONTAL PLANE**

Gait abnormalities in the frontal plane also often occur following MLKI. The most common abnormalities are a varus thrust with varus bony alignment in the frontal plane, which can be termed a “double varus” pattern, or a combination of varus thrusting into the frontal plane with hyperextension, termed a “triple varus” gait pattern. The varus thrust gait pattern (Figure 4) is typically seen in an individual with anatomic varus aligned knees, in the presence of lateral joint laxity or lateral collateral ligament injury. During the stance phase of gait, the patient thrusts laterally, creating tensile forces on the lateral knee and compressive forces on the medial knee structures. The double varus knee thrusts laterally during stance phase of gait, as it simultaneously thrusts into hyperextension creating stress on the lateral and posterior lateral knee structures, specifically the posterior lateral corner of the knee. In the presence of a lateral collateral ligament injury, the cruciate ligaments now serve as the primary stabilizers to varus and valgus movements. In a patient with MLKI involving the lateral collateral ligaments, posterior lateral corner, and the cruciate ligaments, the knee becomes dependant on the dynamic stabilizers to resist this abnormal frontal plane movement. If the quadriceps and hamstring muscles are unable to provide the required dynamic stability during loading response and stance phase, continued stress is placed on the lateral structures of the knee. In addition, if patients adopt this gait pattern in a post operative situation following reconstructive procedures on the cruciate ligaments or the lateral/posterior lateral knee joint, continued high tensile loads on these healing tissues can result in tissue failure.

**PATHOLOGIC GAIT AS A RESULT OF A MLKI: TRANSVERSE PLANE**

Pathologic thrusts and gait abnormalities may also be observed in the transverse plane during the stance phase of gait as the result of knee laxity following a MLKI. Again, an initial position of knee hyperextension and a varus alignment of the knee facilitate such a gait pattern. The “triple varus gait pattern” was described by Noyes et al as a syndrome combining a varus osseous alignment of the knee joint, lateral tibiofemoral compartment separation due to LCL insufficiency, and knee hyperextension with involvement of the PCL. Together, this combination of abnormalities can result in a thrusting gait pattern with pathologically increased tibial rotation. The thrust can occur during the stance phase of gait, as the knee thrusts into a varus-hyperextended position, with subsequent traction force at the lateral compartment. In addition, a rotational force can occur at the tibiofemoral joint. When the tibia is internally rotated, this force is accentuated and it is decreased with external tibial rotation. As has been observed in gait abnormalities that involved a near extended or hyperextended knee position in stance phase, a relative reduction in the quadriceps muscle ability to eccentrically control the movement of the knee from near full extension at initial contact to 20 degrees of flexion during loading response is often demonstrated. If the patient has an underlying quadriceps muscle weakness, either due to injury or recent surgery, the patient may avoid this position due to lack of dynamic stability, an abnormal gait pattern, or a motor pattern may be adopted to successfully compensate for the task.

The potential adverse outcomes as a result of these abnormal gait patterns are substantial. Following a MLKI that is being managed conservatively, a need exists to protect healing tissues during gait and rehabilitation. Abnormal gait patterns that place excessive tensile forces on healing tissue may prolong or deter ultimate healing of the injured ligaments. Similarly, in a post operative scenario, reconstructed or repaired tissue must also be considered to allow for adequate healing time. Therefore, abnormally high repetitive tensile loads during gait must be controlled. In addition to the short term consequences of altered gait, such as altered healing of ligaments, a long term sequelae may exist as well. Stergiou et al theorized that the excessively high tibial rotations occur during gait in patients with an ACL deficient and ACL reconstructed knee and it may be an underlying mechanism for the development of osteoarthritis. These authors suggest that the abnormally high shearing that occurs following ACL injury, or in patients with a MLKI, places abnormally high forces on the articular cartilage, which may ultimately result in early cartilage tissue breakdown. Therefore, current evidence indicates that gait re-training may be a critical component to successful short term and long term outcomes for patients following MLKI and reconstruction.
GAIT RE-TRAINING

Gait re-training has been described previously by several authors as a key component to successfully resuming activity following a MLKI or surgery. If a patient demonstrates an abnormal gait pattern either post injury or post-operatively, an abnormally high tensile or torsional stress will be placed on healing tissues, which could potentially deter or interrupt the healing and maturational process of the ligament. Essentially, two components are required for the successful implementation of a gait re-training program. First, the patient must possess or develop sufficient underlying quadriceps muscle strength to safely ambulate. Many of the abnormal gait patterns observed following a MLKI are in part or entirely related to the knee in a hyperextended position, which results in decreased demand on the quadriceps femoris muscle, as a potential means of compensation for insufficient strength. Typically following injury and surgery, a marked deficit in quadriceps muscle strength occurs. Therefore, the physical therapist must first address any underlying quadriceps muscle strength impairments prior to implementing, or in conjunction with, the gait re-training component of the plan of care. Only after adequate strength development and motor activation is achieved can the patient be expected to feel sufficiently comfortable and confident to develop a gait pattern that is dependent on quadriceps muscle strength and the ability to fluidly activate and control concentric and eccentric activation of the quadriceps muscle. Following the development of the required level of quadriceps muscle strength, the next phase of gait re-training should focus on the development of the normal biphasic pattern of sagittal plane motion during stance. Typically, the development of the progression of knee flexion from 0 degrees at initial contact to 20 degrees during loading response should be the focus. Neuromuscular facilitation exercises and activities during gait or with supplemental interventions such as a heel lift can be utilized. Neuromuscular re-education during gait training should focus on early knee flexion following initial contact, and controlled progression of knee flexion during loading response, in addition to maintenance of an upright trunk posture to facilitate hip extensor activation. Heel lifts can force the knee into a flexed position following initial contact, also allowing for increased facilitation of quadriceps muscle contraction during this phase of gait.

The efficacy of a pre-surgery gait re-training program was investigated by Noyes et al. The authors categorized gait abnormalities in this population into two distinct patterns, with the efficacy of a gait re-training program reported for each pattern. These authors described a Type II gait pattern, which was defined as a hyperextension, whereby the patient maintained a hyperextended knee throughout stance. They also described a Type I gait pattern in which the patient demonstrated a quick "back and forth" motion into flexion and hyperextension while progressing through stance. Noyes et al implemented a gait re-training program in both cohorts and reported greater success with gait re-training, especially in the ability to normalize sagittal plane kinematics during a normal gait cycle, in the Type II (hyperextend knee) pattern patient when compared to those with rapid and oscillatory sagittal plane knee movement during stance.

SUMMARY AND CONCLUSION

A MLKI can potentially be a devastating and limb threatening injury for patients. Understanding the underlying biomechanics of the static and dynamic stabilizers of the knee provides a framework to develop an efficacious and safe treatment plan to address underlying impairments with the goal of maximizing dynamic stability of the knee, while protecting the static stabilizing structures. Gait re-training is an important component of any treatment plan to ensure high tensile loads are not being placed on healing tissue, which could ultimately result in ligament failure. If the patient is able to successfully address the impaired function, quadriceps muscle weakness, and gait abnormalities successfully, the patient may be progressed through the early and end stages of rehabilitation without underlying tensile stresses that often coincide with these gait abnormalities and long term failure.

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