Review Article

How to avoid tunnel convergence in a multiligament injured knee

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Abstract: Multiligament knee injuries are challenging to diagnose and treat. For knee dislocations surgical treatment of the torn ligaments has been demonstrated to be superior to non-operative management. Furthermore, reconstruction of the torn ligaments has been demonstrated to be superior to repair of the torn ligaments. Repair of knee ligaments is associated with higher failure and reoperation rates compared to reconstruction; therefore, anatomic reconstruction of the torn ligaments is recommended. It is imperative to perform anatomic reconstructions to restore both the anatomy and the biomechanics of the knee. When reconstructing several knee ligaments, there is a risk of tunnel confluence in both the femur and the tibia. Prior to and during surgery, thorough planning of tunnel placement and orientation is important.

Keywords: Multiligament knee injury; knee ligament reconstruction; tunnel convergence

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Introduction

A multi-ligament knee injury is defined as a tear of at least two of the four major knee ligament structure complexes: the posterior cruciate ligament (PCL), the anterior cruciate ligament (ACL), the posterolateral corner (PLC) and the posteromedial corner (PMC) (*Figure 1*) (1,2). These injuries are less common than isolated knee ligament injuries; however, identifying and diagnosing these complex and challenging injuries is important. Knee dislocations result in multiligament knee injuries; however, multiligament knee injuries can occur in the absence of a knee dislocation. A high level of suspicion, and a thorough and systematic evaluation of the patient is mandatory to diagnose these injuries because a missed diagnosis can lead to persistent instability, pain and ligament reconstruction failure if all torn ligaments are not addressed concurrently.

Knee ligament injury patterns and epidemiology

Despite being less common than isolated knee ligament tears, multiligament knee injuries are not as rare as previously reported (3). Medial side structures are commonly injured in multiligament knee injuries occurring after knee dislocations (4). Grade III medial-sided injuries have a concomitant cruciate ligament injury in 78% of the cases (5). In a setting of bicruciate knee dislocations, medial sided injuries have been reported to occur in 17–52% of the cases (4,6). Injuries to the PLC and fibular collateral ligament (FCL) are typically associated with concomitant knee ligament injuries such as ACL and PCL tears (5-7). In a series of 102 patients with acute PLC injuries, isolated PLC injuries were found in only 28 patients. Thus, patients with high grade (grade III) medial or lateral collateral ligament tears should be evaluated for combined injuries.

Figure 1 AT1 weighted MRI (3T) of a right knee in a patient with a multiligament knee injury. The image on the left is a sagittal view showing anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) tears. The image on the right is a coronal view of a right knee showing injuries to the superficial medial collateral ligament (sMCL) as well as the posterolateral corner (PLC).

Moatshe *et al.* evaluated 303 patients with bicruciate knee dislocations, and reported that 52% had medial-sided injuries (KD IIIM), 28% had lateral sided injuries (KD IIIL) and 13% had injuries to all four major knee stabilizers (KD IV) (4). These findings demonstrate that up to 83% of patients with multiligament knee injuries after a knee dislocation will require reconstruction of three or more ligaments. In all knee injuries, especially high energy injuries, it is important to evaluate the integrity of all ligaments. A thorough and systematic evaluation of the knee is imperative to identify all the injured structures, develop a management plan and to optimize functional outcomes. Furthermore, the use of imaging, including magnetic resonance imaging (MRI), to diagnose concomitant injuries (*Figure 1*), and stress radiographs to evaluate the extent of ligament injury is recommended. This is particularly important in chronic cases where MRI has been demonstrated to have lower sensitivity for PCL and FCL tears compared to stress radiographs (7,8).

Treatment of multiligament knee injuries

Non-operative treatment

Grade I and II ligament injuries whether isolated, or in multiligament injured knees, are usually treated non-operatively. Non-operative treatment of knee ligament injuries usually involves bracing for 5–7 weeks and physical rehabilitation programs that focus on restoring knee range of motion, proprioception and patella mobility, enhancing quadriceps function, and controlling edema (9). However, the type of brace, duration of bracing and the rehabilitation protocol depends on the concomitant knee ligament injuries.

Operative treatment

Surgical treatment of grade III ligament injuries in the setting of multiligament knee injuries has been demonstrated to result in superior clinical outcomes compared to non-surgical treatment (1,10-14). Reconstruction of the cruciate ligaments is widely accepted, and is regarded as the standard of treatment despite recent increasing interest in surgical repair of the torn cruciate ligaments (15). Studies have reported higher failure and reoperation rates after repair of the collateral ligaments compared to reconstructions (16,17). Thus, it is usually recommended to reconstruct both the cruciate (18-21) and collateral ligaments (16,17) when torn. Anatomic knee ligament reconstruction has

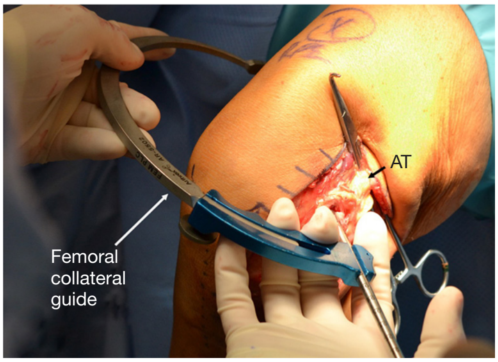

Figure 2 An intraoperative image of a right knee showing reconstruction of the superficial medial collateral ligament (sMCL) in a multiligament injured knee. To avoid confluence with the posterior cruciate ligament (PCL) tunnels, it is recommended to aim the sMCL tunnel anteriorly and proximally. AT, adductor tubercle.

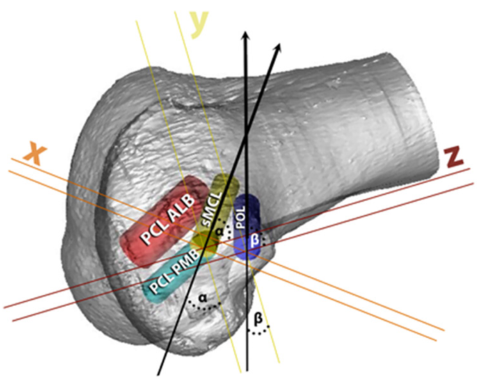

Figure 3 An illustration demonstrating reconstruction tunnels in the medial femoral condyle in a left knee. The risk of tunnel convergence in the medial femur condyle is high when four reconstruction tunnels are created. Aiming the sMCL tunnel 40° proximally and 20–40° anteriorly minimizes the risk of convergence with the PCL tunnels. The POL tunnel should be aimed 20° proximally and 20° anteriorly to minimize the risk of convergence with the PCL. With permission from Moatshe *et al.* (34). PCL, posterior cruciate ligament; ALB, anterolateral bundle; PMB, posteromedial bundle; POL, posterior oblique ligament; sMCL, superficial medial collateral ligament.

been demonstrated to restore the native anatomy and biomechanics. Furthermore, it is recommended that all injured structures be reconstructed concurrently in order to minimize the risk of reconstruction graft failure and to allow for early knee motion (22-25). Biomechanical studies have demonstrated that untreated grade III PLC injuries increase the forces on both the ACL and PCL, which can increase the risk of graft failure (23,24).

The qualitative and quantitative anatomy of the native knee ligaments, which is the basis for optimal tunnel placement for anatomic reconstruction of knee ligament structures have previously been defined (26-33). In the setting of multiligament reconstruction in the knee, several tunnels are needed for the reconstruction grafts in both the distal femur and proximal tibia and the risk of tunnel convergence is high. When reconstruction tunnels converge, the reconstruction graft can be damaged and increase the risk of reconstruction failure. Additionally, damage to fixation devices and poor graft fixation can occur, leading to reconstruction failure. Furthermore, creating several tunnels may lead to bone loss and there may not be sufficient bone stock for graft fixation, incorporation and healing.

Avoiding tunnel convergence

Femoral tunnels

In the setting of global laxity where all four major knee ligament structures are torn, there will potentially be four tunnels or sockets [double bundle PCL, sMCL and posterior oblique ligament (POL)] in the medial femoral condyle and three on the lateral femoral condyle [ACL, FCL and popliteus tendon (PLT)]. Aiming the collateral ligament tunnels, POL and popliteus tunnel straight across the distal femur and parallel to the joint line increases the risk of convergence with cruciate ligament tunnels. On the medial femoral side, Moatshe *et al.* (34) reported that aiming the sMCL tunnel 40° in the axial and coronal planes and the POL tunnel 20° in the axial and coronal planes was safe to avoid convergence with the double bundle PCL tunnels (*Figures 2,3*). Gelber *et al.* evaluated tunnel convergence and optimal angulation of the tunnels on the medial femur condyle, and found that aiming the PMC tunnels (superficial MCL and POL) 30° in the axial plane and coronal plane reduced the risk of convergence with the PCL tunnels (35).

On the lateral femoral condyle, the FCL and popliteus tunnels should be parallel to each other. In a recent study evaluating the risk of tunnel convergence in the femur and the optimal angulation of the tunnels, Moatshe *et al.*, found that aiming both the FCL (lateral collateral ligament) and the PLT tunnels 35–40° anteriorly reduced the risk

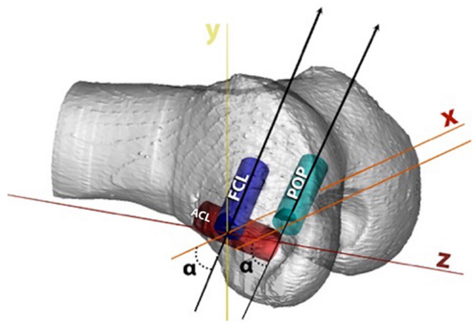

Figure 4 Illustration demonstrating three reconstruction tunnels in the lateral femoral condyle in a left knee. Aiming both the fibular collateral ligament (FCL) and the popliteus tendon (PLT) tunnels 35–40° anteriorly reduces the risk of convergence with the anterior cruciate ligament (ACL) tunnel. With permission from Moatshe *et al.* (34). POP, popliteus tendon.

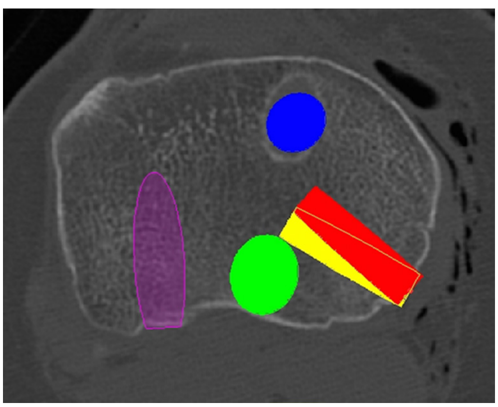

Figure 5 A CT of a right proximal tibia demonstrating different reconstruction tunnels. Aiming the POL tunnel towards Gerdy's tubercle (yellow) increases the risk of convergence with the PCL tunnel (green). By aiming the POL tunnel to a point 15 mm medial to Gerdy's tubercle (red) the risk of convergence with the PCL tunnel (green) can be reduced. The anterior cruciate ligament (ACL) tunnel is shown in blue, and the tunnel for the posterolateral reconstruction on the tibia is shown in purple. With permission from Moatshe *et al.* (43). PCL, posterior cruciate ligament; POL, posterior oblique ligament; ACL, anterior cruciate ligament.

of convergence with the ACL tunnel (*Figure 4*) (34). In addition, Shuler *et al* reported that angles over 40° should be avoided because they lead to elliptical tunnels (36), which can ultimately lead to poor fixation of the reconstruction grafts.

It is important to be aware of the risk of tunnel convergence when treating multiligament injuries and plan tunnel placement and orientation appropriately. Furthermore, the use of perioperative fluoroscopy may be beneficial.

Some authors argue that the MCL has a good intrinsic healing potential and hence can be treated non-operatively, even in multiligament injuries. With this approach, the knee is placed in a brace for 6–8 weeks until the MCL heals, and the other ligaments can be treated surgically at a later stage. This approach allows for early mobilization of the knee to reduce the risk of arthrofibrosis and reduce surgery time. Furthermore, if the MCL heals, the risk of tunnel convergence with the PCL is minimized (37). However, it is important to remember that a multiligament knee injury is more complex, with more soft tissue injury; therefore, the healing potential of the MCL may be compromised by both the large injury and the secondary instability of the knee. Thus, a medial side injury in a setting of a multiligament knee injury is different from an isolated MCL injury. High grade injuries (grade III) of the PMC, specifically tears with valgus gapping in extension and distal tears of the MCL, have a higher risk of not healing, with a resultant residual valgus and rotational instability (38,39). Persistent instability increases the forces acting on the ACL and PCL reconstruction grafts, increasing the risk of reconstruction graft failure. Therefore, in a setting of a multiligament knee injury involving the PMC, early concurrent reconstruction is recommended to facilitate early mobilization and rehabilitation (25).

Tibial tunnels

In a setting where all major knee ligaments are torn (KD IV), there will potentially be a total of 5 tunnels in the proximal tibia when using anatomic and biomechanically validated reconstruction techniques (29,30,40-42). The number of tunnels in the tibia can be increased in the setting of meniscal root repair with transtibial technique. Moatshe *et al.* (43). reported that the rate of tunnel convergence between the POL and the PCL tunnels in the tibia when the POL tunnel was aimed at Gerdy's tubercle was 67%. This high convergence rate can lead to reconstruction graft failure. The risk of tunnel convergence between the POL and the PCL can be minimized by aiming the POL tunnel to a point 15 mm medial to Gerdy's tubercle (*Figure 5*). There is an increased risk of tunnel convergence between the PCL tunnel and the superficial

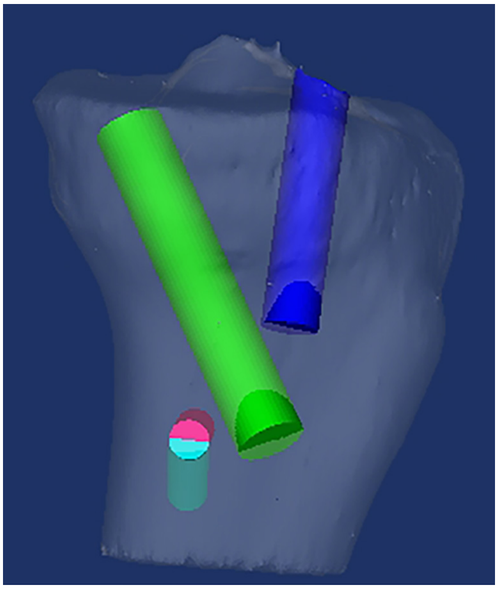

Figure 6 A 3D model showing multiple tunnels in the tibia when ACL (dark blue), PCL (green) and sMCL (pink) are reconstructed. There is an increased risk of convergence between the PCL tunnel (green) and the sMCL (pink) tunnel when drilled horizontally and parallel to the joint line. By aiming the sMCL tunnel 30° distally (light blue), the risk of convergence with the PCL tunnel can be reduced. With permission from Moatshe *et al.* (43). ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; sMCL, superficial medial collateral ligament.

medial collateral ligament (sMCL) tunnel, both of which are created 6 cm from the joint line on the tibia. In a study using 3DCT and Mimics software to recreate anatomic reconstructions, Moatshe *et al.* recommended that the sMCL tunnel be aimed 30° distally to avoid convergence with the PCL (*Figure 6*) (43). In smaller knees, the PLC tunnel may be too close to the PCL tunnel posteriorly, it is imperative to use the anatomic landmarks to ensure correct placement of the tunnels to avoid convergence. Fluoroscopy can also be utilized preoperatively to verify pin placement prior to reaming.

Summary

Multiligament knee injuries are challenging to diagnose and treat. Surgical treatment of the torn ligaments has been demonstrated to be superior to non-operative management. Furthermore, reconstruction of the torn ligaments has been demonstrated to be superior to repair. In the setting of multiple knee ligament reconstructions, the risk of tunnel convergence is high because of the total number and size of the tunnels in a limited bone mass. It is recommended to perform anatomic ligament reconstructions to restore both the anatomy and the biomechanics of the knee. Thorough planning of tunnel placement and orientation is important.

On the medial femoral condyle, aiming the sMCL tunnel 40° proximally (towards the hip) and 20–40° anteriorly in the axial plane can reduce the risk of collision with the PCL tunnels. If there is a concurrent POL reconstruction, the sMCL tunnel should be aimed 40° proximally and 40° anteriorly, and the POL tunnel should be aimed 20° proximally and 20° anteriorly to minimize the risk of convergence with the PCL tunnels. On the lateral femoral condyle, it is recommended to aim both the FCL and the PLT tunnels 35–40° anteriorly to reduce the risk of convergence with the ACL tunnel.

On the proximal tibia, aiming the POL towards Gerdy's tubercle increases the risk of convergence with the PCL tunnel; therefore, it is recommended to aim the POL tunnels to a point 15 mm medial to Gerdy's tubercle to reduce risk of convergence with the PCL tunnel. If the sMCL is reconstructed concurrently with the PCL, convergence between the tunnels can be minimized by aiming the sMCL 30° distally. Good exposure to identify the anatomic landmarks and the use of intra-operative fluoroscopy can facilitate better tunnel placement and orientation.

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Footnote

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