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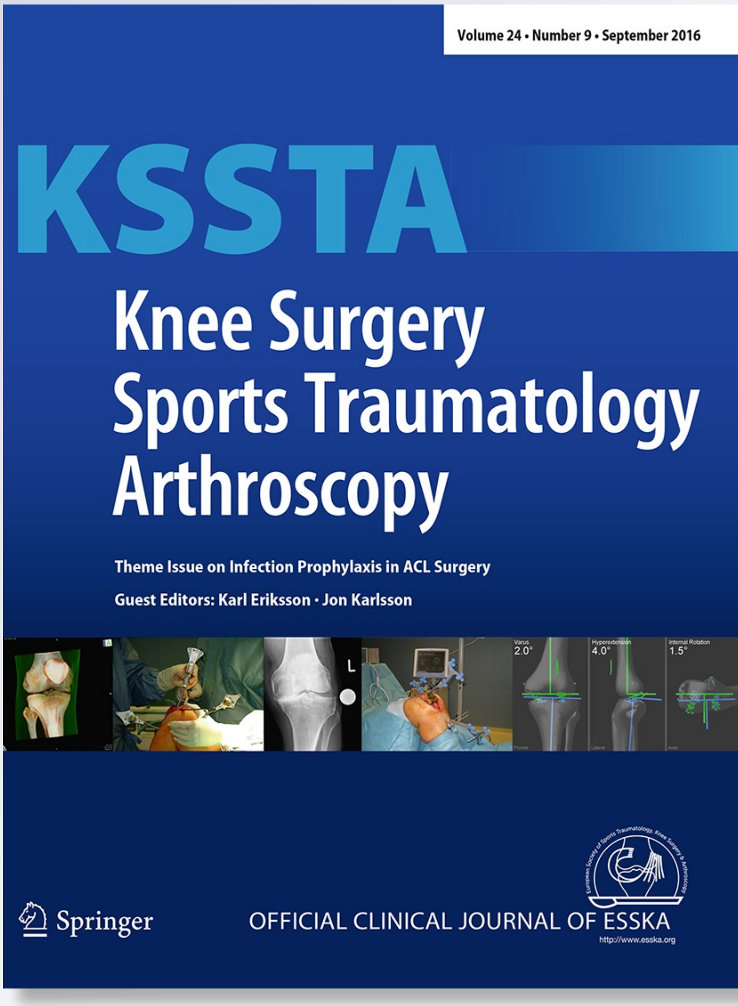

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How to avoid collision between PCL and MCL femoral tunnels during a simultaneous reconstruction

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Abstract

Purpose The purpose of the present study was to assess the risk of femoral tunnel collisions between the medial collateral ligament (MCL) and the posterior cruciate ligament (PCL) tunnels during a simultaneous PCL and MCL reconstruction.

Methods Fourth generation medium and large synthetic femur bones were used. On each femur, a MCL tunnel and a PCL tunnel were reamed. The MCL tunnel was drilled at 0°, 20° and 40° of axial and coronal angulations. The PCL femoral tunnel was reamed to simulate two different tunnel directions that could be obtained through an inside-out and outside-in technique. Tunnels were filled with epoxy resin augmented with $BaSO_4$, and a multidetector CT examination of each specimen was performed.

Results High rate of tunnel collision (62.5 %) was found when the MCL femoral tunnel was reamed with a coronal angulation of 0° and 20°. The rate of tunnel collision significantly decreased (0 %) when the MCL tunnel was reamed proximally with a coronal angulation of 40°. No differences were found between the two PCL tunnel directions in terms of tunnel collision.

Conclusion The results of this study can help surgeons to better direct the femoral MCL tunnel in order to avoid a collision between femoral tunnels during a combined MCL and PCL reconstruction. In order to minimize such potential complications, the MCL tunnel should be created limiting the axial angulation and it should be drilled with a proximal angulation from 20° to 40°, depending on the medial condyle width.

Keywords Medial collateral ligament · Multiple ligament reconstruction · MCL PCL · Posterior cruciate ligament reconstruction · Medial collateral ligament reconstruction · Combined ligament reconstruction

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Introduction

Injuries to the medial collateral ligament (MCL) and posteromedial corner of the knee are very common and can occur in an isolated pattern or combined with anterior or posterior ligament lesions. For low grade MCL injuries, non-operative treatment has been represented as the choice for most cases [5, 6, 11, 13, 22]. Recently, following an increased knowledge of knee biomechanics and ligaments function, an awareness was observed on treating peripheral knee ligament injuries in the setting of a concurrent cruciate reconstruction, with primary repair within 2 weeks after the injury and secondary reconstruction in chronic cases [2, 7, 20]. In the last occurrence, several techniques of MCL reconstruction have been described to date and almost all of them differ from graft choice and distal tibial fixation [4, 14, 15, 17, 28]. However, all of them require to drill a medial femoral tunnel for graft placement, with an anatomic or isometric location.

In cases of combined anterior cruciate ligament reconstruction (ACL), the MCL femoral tunnel could be placed in any direction because of different condyle tunnel placements. Otherwise, in case of simultaneous MCL and posterior cruciate ligament (PCL) reconstruction, two tunnels are created in the same condyle and close to each other. In this circumstance, the MCL tunnel orientation may place the PCL tunnel at risk of collision that could compromise the graft fixation and its integrity. Even different surgical techniques for MCL reconstruction have been described, none of them accurately describes the direction of MCL tunnel, especially during multi-ligament reconstruction. Other studies evaluated the risk of femoral tunnel collision during a combined ACL/PCL and posterolateral corner reconstruction [3, 8]. However, to our knowledge, no study has assessed the feasibility of femoral tunnel creations during a combined PCL and MCL reconstruction.

The purpose of the present study is to assess the risk of femoral tunnel collisions between the MCL and PCL tunnels using synthetic femurs. Furthermore, a second purpose is to determine the best location for both tunnels to avoid tunnel collisions. The hypothesis is that a more proximal orientation of the MCL femoral tunnel should reduce the risk of collision with the PCL femoral tunnel.

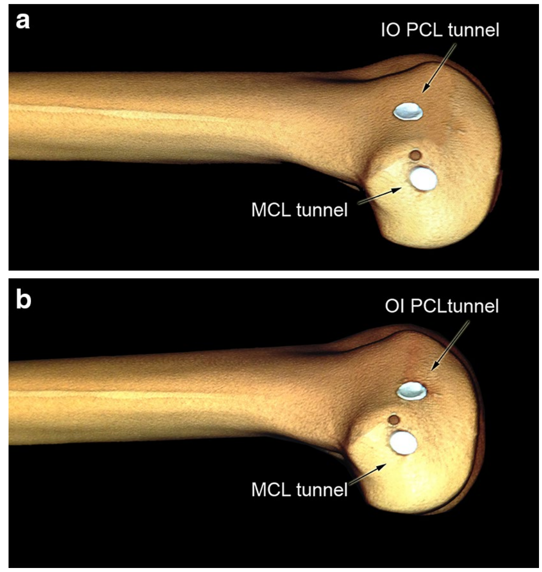

Fig. 1 Medial view of a synthetic femur. On each femur, a MCL tunnel and a PCL tunnel were reamed. Note the different exit point of the inside- out (IO) (**a**) and outside-in (OI) (**b**) PCL femoral tunnel

Materials and methods

For this study, thirty-six fourth generation synthetic femur bones were used (Sawbones, Pacific Research Laboratories, Vashon, WA). Two different femur sizes were employed. Specifically, eighteen medium and eighteen large femurs were used with a medial femoral condyle width, respectively, of 26 and 34 mm. On each femur, a MCL and a PCL tunnel were performed.

The PCL footprint was anatomically located on the medial condyle wall and then confirmed under fluoroscopy using a K-wire as previously described [12]. A guide wire was then drilled through the centre of the femoral anterolateral bundle PCL footprint to the medial femoral cortex using a FlipCutter PCL femoral guide (Arthrex, Inc.). Based on a previous study that demonstrates different degrees of femoral tunnel using either an outside-in or an inside-out tunnel creation, two exit points on the medial femoral cortex were chosen [23]. In this way, an outside-in or an inside-out PCL femoral tunnel was created on each femur with an angulation of 21° and 37°, respectively, in the anteroposterior radiograph view and 27° and 39°, respectively, in the axial view. Correct placement of the guide wires were confirmed through radiographs, and degree measurements were obtained with the use of a goniometer. In this phase, value <2° was considered acceptable for the study. Once the correct degree was obtained, a full 8-mm femoral tunnel was reamed (Fig. 1) [24]. Concerning the MCL femoral reconstruction tunnel, a guide wire was anatomically placed on the medial epicondyle and the correct position of the MCL footprint was confirmed through both AP and lateral radiographs as described by Wijdicks et al. [27]. The guide wire was then reamed from the medial epicondyle to the lateral femoral cortex, parallel to the posterior femoral condyle line and to the tangent line of the distal ends of the medial and lateral femoral condyle [2]. From this position (0; 0), 20° intervals in both the coronal and axial planes were used to create the MCL tunnel, obtaining nine different tunnel orientations (Fig. 2). As for PCL tunnel creation, radiographs and degree measurements were obtained to evaluate the correct placement of the guide wire. At this point, a 7-mm tunnel was reamed over the guide wire to a depth of 25 and 30 mm [4, 28]. In this phase, tunnel collisions were analysed and recorded.

Specimens that did not present obvious tunnel convergence was secondary treated by filling the tunnels with an epoxy resin augmented with $BaSO_4$. Multidetector CT with 1.3 mm slice thickness was performed on synthetic specimens, and 3D volume rendering CT reconstructions were carried out. Three-dimensional images were then obtained to determine and analyse tunnels' positions. Further, a radiologist blinded to the subject and purpose of the study analysed the shortest distance between MCL and PCL tunnel in all planes.

Statistical analysis

Thirty-six tunnel permutations were obtained in thirty-six femurs. For each parameter (PCL-OI/PCL-IO; MCL permutation), collision frequencies were calculated. Further, coronal MCL tunnel permutations were dichotomized (O-20° = 1; 40° = 2), and Chi-square test was used to compare data (collision/no collision; PCL-OI/PCL-IO).

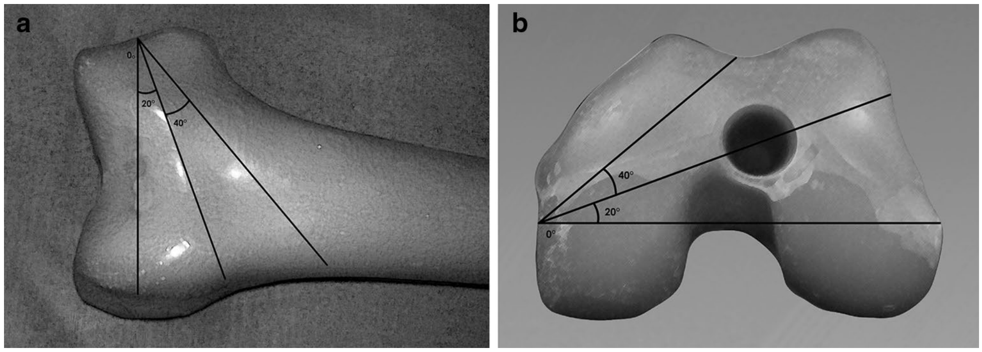

Fig. 2 The MCL tunnel was drilled at 0°, 20° and 40° of axial and coronal angulations creating nine different tunnel orientations

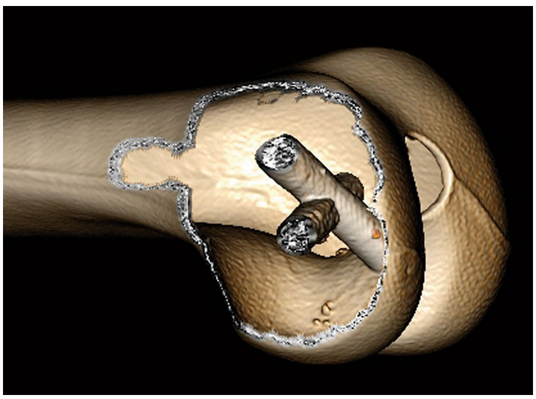

Fig. 3 3D reconstruction of a medium synthetic femur (0°:20° MCL/IO-PCL). Tunnel intersection occurred when the MCL tunnel was reamed with no proximal deviation. This was independent from the direction of PCL tunnel

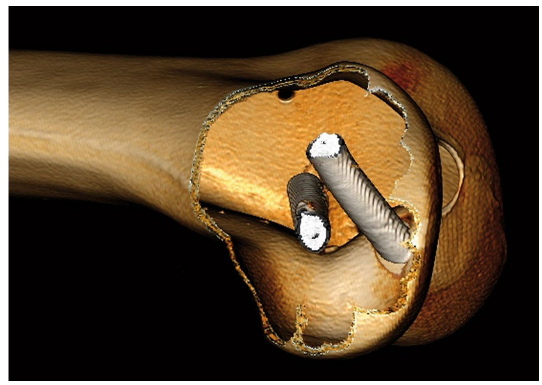

Fig. 4 3D reconstruction of a large synthetic femur (20°:20° MCL/IO-PCL). No collision occurred in large femurs when the MCL tunnel was reamed with proximal deviation of 20°

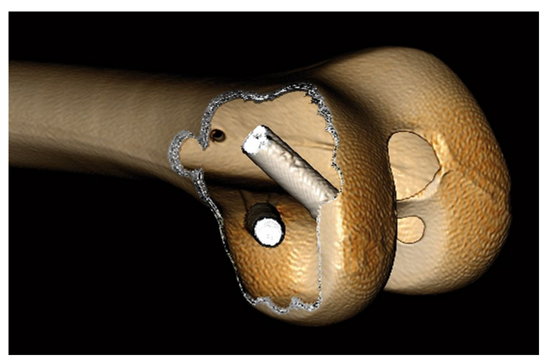

Fig. 5 3D reconstruction of a medium synthetic femur (40°:0° MCL/IO-PCL). No collision was noted between the PCL-IO tunnel and the MCL tunnel when this was reamed parallel to the posterior condylar line and with coronal angulations of 40°

Statistical analysis was performed using SPSS 11 (SPSS, Chicago, IL), and the level of significance was $p \leq 0.05$ for all analyses.

Results

The overall rate of tunnel collision when the MCL tunnels were reamed to a depth of 25 and 30 mm was, respectively, 39 and 44 %. No differences were noted in terms of tunnel collision concerning inside-out or outside-in femoral tunnels (n.s.). The rate of tunnel collision was significantly higher when the MCL tunnel was reamed parallel to the distal condylar line in all axial permutations compared with the MCL tunnel reamed with 20° and 40° of coronal angulation ($p < 0.001$) (Fig. 3). Specifically in large femurs, when MCL tunnels were reamed with 0° of proximal angulation, a collision rate of 100 and 83 %, respectively, for femoral tunnel depth of 30 and 25 mm was observed. In these tunnel configurations and in medium femurs, 100 % tunnel collisions were observed.

At 20° of proximal angulation of the MCL tunnel, no collision was observed for all axial angulation values in large femur specimens [mean minimum tunnel distance of 3.9 mm ± 3.5 (range 1–10.7)]. However, in medium femurs and at these degrees of proximal angulation, a 67 %

Table 1 Minimum distance between the MCL and PCL tunnels when the MCL tunnel was reamed with a proximal deviation of 20°/40° and with axial angulations of 0°, 20° and 40°

	Medium Femur		Large Femur	
Coronal deviation	20°	40°	20°	40°
In–out PCL tunnel				
AXIAL 0° MCL tunnel	3.3	5.3	10.7	14.2
AXIAL 20° MCL tunnel	–	6.1	1.8	8.5
AXIAL 40° MCL tunnel	–	6.5	1	5.5
Out–in PCL tunnel				
AXIAL 0° MCL tunnel	1.2	4.8	6.4	10.8
AXIAL 20° MCL tunnel	–	4.1	2.7	9.3
AXIAL 40° MCL tunnel	–	3.3	1	5

Values expressed in millimetres (mm)

of tunnel collision was observed. Furthermore, in medium femurs, all collisions occurred when the MCL was reamed with an axial deviation of 20° and 40° (Fig. 4).

When the MCL femoral tunnel was reamed with a proximal deviation of 40°, no collisions were observed in all specimens independently from axial angulation. This was present for both femur sizes and for all MCL tunnel depth.

In this circumstance, mean minimum distance between MCL and PCL femoral tunnels was of 8.9 mm ± 3.1 (range 5–14.1 mm) and 5 mm ± 1.1 (range 3.3–6.5), respectively, for large and medium femurs (Fig. 5; Table 1).

Discussion

The most important finding of the present study was that there is a high risk of collisions between femoral tunnels when the MCL is being reconstructed in setting with the PCL. However, it was found that tunnel collision could be avoided by directing the MCL femoral tunnel proximally, with a coronal angulation from 20° to 40° limiting the axial angulation. In this situation, tunnels become divergences decreasing the potential tunnel intersection.

The MCL is one of the most frequently injured ligaments of the knee. Even if functional brace and early rehabilitation represent the best treatment for most acute MCL lesions, in case of multiple ligament injuries surgical reconstruction is recommended, especially in the presence of combined ACL or PCL injuries [25, 28]. In fact, it has been shown that in cases of the multi-ligamentous-injured knees, untreated posteromedial instability can be considered a cause for failure of a PCL reconstruction [9]. In the last decade, several authors described different surgical techniques for MCL reconstruction. In addition, femoral insertion site has been carefully described both anatomically and radiographically. However, none of them accurately describes the direction of MCL tunnel although it seems to play an important role, especially during multi-ligament reconstruction due to a risk of tunnel convergence. In fact, in such a situation, a bone weakening, loss of graft fixation and grafts impairment could occur, compromising the entire ligament surgery.

In this study, MCL tunnel trajectories were limited to a range of 0–40° on coronal and axial view, with a permutation of 20° on both planes. Using nine MCL tunnel permutations, it was observed that a coronal deviation of 20° or 40° was able to avoid tunnel convergence in large femurs. This was observed for all axial permutations. Otherwise, in medium femurs, proximal deviation of 20° produced a high risk of collision (67 %), with no intersection observed when the MCL tunnel was reamed with no axial deviation and parallel to the posterior femoral condyle line (20°–0°). Furthermore, the minimum distance between tunnels observed on CT images have been shown to increase passing from 20° to 40° of coronal angulation.

In respect to the MCL femoral tunnel, it was observed that the tunnel depth plays an important role on tunnel collision only when the tunnel is reamed parallel to the distal condylar line. This was observed only on large femur sizes. In fact, at 25 mm tunnel depth, no collision was detected, while a collision was recorded near the femoral notch when the MCL tunnel was reamed to a depth of 30 mm.

The PCL consists of two major bundles, namely the anterolateral and posteromedial bundle based on ligament functions in flexion and extension [10, 18, 19]. As the ACL, the PCL could be reconstructed by creating a single or a double-bundle technique. Even if biomechanical studies analysed the merits of a double-bundle reconstruction, no clear clinical benefit has been demonstrated over the single-bundle technique [1, 10, 21, 26]. For this reason, in our study, it was preferred a single femoral tunnel that was placed and centred in the footprint of the anterolateral bundle. Further, the femoral PCL tunnel could be created through an outside-in or an inside-out technique. In these two cases, it was observed a significant difference in orientation of the femoral tunnels [23] with a tunnel placement that is closer to the main posteromedial structures. For this reason, two different orientations of the femoral PCL tunnel were chosen in our study to mimic two different tunnel angulations that could be obtained through an outside-in or an inside-out technique. We supposed that a more anterior and vertical orientation of inside-out tunnels versus the outside-in tunnels can increase the minimum distance between PCL and MCL tunnels. In spite of this, differences on tunnel collisions were not found when the two tunnels were compared (outside-in vs inside-out). This could be justified by a large degree of femoral MCL tunnels permutation (20°). However, we believe that PCL femoral tunnel performed with the inside-out technique could reduce the risk of tunnel collision when a MCL reconstruction is performed in setting with a PCL reconstruction. In fact, a lower PCL femoral tunnel created through the outside-in technique and placed closer to the entry point of the MCL tunnel could increase the risk of tunnel intersection. This could be more evident in cases of small femoral condyle due to a smaller available volume for traversing tunnels.

In this study, just a 7-mm MCL and 8-mm PCL femoral tunnels were evaluated. We are aware that in the clinical setting and especially for the PCL, the femoral tunnel diameter could increase to 9–10 mm specifically in case of allograft implantation [16]. However, the choice of using 8-mm PCL tunnel was made upon the possibility to increase the amount of femurs studied with CT for minimum distance measurement. Further, diameters chosen for the drilled tunnels were intended to be similar to those used in clinical situations using 4-strand hamstring tendon autograft [24]. Based on minimum distance between tunnels observed in this study, we believe that increasing tunnel diameters could result in an increased risk of tunnel collisions.

Concerning the risk of collision, we found that small femoral condyle size represents a major risk factor for tunnel intersection. In fact, in medium femurs, a higher tunnel collision was found compared to large femurs. In the clinical setting, we suggest measuring the width of the medial femoral condyle before tunnel reaming considering that in cases of medial femoral condyle <34–32 mm, it should increase the proximal MCL tunnel deviation 40°. Furthermore, in order to avoid tunnel convergence, adequate distance on the cortical medial condyle of PCL and MCL should be evaluated as a short distance could increase tunnel intersection.

The present study has some limitations. First, synthetic specimens do not reflect accurately the variability of human femurs. Indeed, in vivo tunnel creations may produce different findings. Several studies assessed the knee anthropometry with distinct difference in size between gender and ethnicity. However, we believe that the use of medium and large femurs could reflect different condyle sizes that are expected in "in vivo" circumstances, respectively, in white females and males [29]. Secondly, just 8-mm full PCL tunnel and 7-mm MCL-drilled tunnels were evaluated. We are aware that increasing tunnel diameters could result in an increased risk of tunnel collisions. Thirdly, the femoral posterior oblique ligament (POL) tunnel placement was not evaluated. In fact, several authors suggest to reconstruct the POL in the setting of the MCL reconstruction [4]. However, POL tunnel is placed posteriorly, and this should increase its distance from the PCL tunnel. Finally, MCL and PCL tunnel angles partially reproduce those angles that could be obtained in the clinical setting. This may limit the generalizability of the current results to in vivo reconstructive procedures. Nonetheless, the results of this study can help surgeons to better direct the femoral MCL tunnel in order to avoid a collision between femoral tunnels during a combined MCL and PCL reconstruction. Further, surgeons should be aware that the small medial femoral condyle represents the major risk factor for tunnel intersection.

Conclusion

The results of the present study have shown that the risk of tunnel collision between MCL and PCL femoral tunnel is high. However, surgeons should be aware that it could be avoided by limiting the axial angulation of the MCL tunnel and directing it proximally between 20° and 40° of coronal angulation, depending on the medial condyle width.

Conflict of interest The authors declare that they have no conflict of interest related to the publication of this manuscript.

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