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Abstract

This review paper describes anteromedial rotatory laxity of the knee joint. Combined instability of the superficial MCL and the structures of the posteromedial corner is the pathological background anteromedial rotatory laxity. Anteromedial rotatory instability is clinically characterized by anteromedial tibial plateau subluxation anterior to the corresponding femoral condyle. The anatomical and biomechanical background for anteromedial laxity is presented and related to the clinical evaluation and treatment decision strategies are mentioned. A review of the clinical studies that address surgical treatment of anteromedial rotatory instability including surgical techniques and clinical outcomes is presented.

Introduction

It is well accepted that the superficial medial collateral ligament is a primary static stabilizer preventing anteromedial rotatory instability (AMRI), valgus translation, external rotation and internal rotation about the knee. [11,35] It has also been reported that the posterior oblique ligament (POL) is an important primary restraint to internal rotation and a secondary restraint to valgus translation and external rotation. [10,28] A high frequency of combined superficial medial collateral ligament (sMCL) and POL injuries have been reported in knees with acute or chronic valgus laxity, signifying the important role of the POL in providing static stabilization to the medial knee.[13] Furthermore, untreated acute isolated or combined superficial medial collateral or POL injuries have been reported to result in functional limitations and osteoarthritis.[17] Therefore, intensive rehabilitation of these common injuries may be necessary in some circumstances to prevent the pathologies associated with chronic medial knee instability.

Slocum and Larson first described the term AMRI. [31] This instability was described as excessive valgus motion coupled with external rotation of the knee. This occurs when the anteromedial tibial plateau subluxates anterior to the corresponding femoral condyle. The posteromedial corner has been shown to serve as an important restraint to AMRI throughout the normal range of motion. [29]

Historic treatment of acute medial collateral ligament injuries has focused on non-operative therapies with early controlled motion with relatively good reported patient outcomes. [5,15,24] However, more severe acute and symptomatic chronic medial knee injuries may require operative management. Injuries that involve all medial and posteromedial structures, the superficial MCL, the deep MCL, the (POL), and the posterior capsule are characterized as a grade 3 injury and has a greater risk of developing chronic medial and rotatory instability requiring surgical treatment. [37] [33]. Current described surgical techniques for medial collateral stabilization include direct repair of the medial structures, [14] primary repair with augmentation, [7] advancement of the sMCL tibial insertion site, [26] pes anserinus transfer, [30] advancement with pes anserinus transfer, [26] and non-biomechanically validated reconstruction techniques. [38,2,8]

Few biomechanically validated anatomic reconstruction techniques using quantitatively described anatomic data [22,37] to design reconstruction techniques of the sMCL and POL injuries have been reported. An anatomic reconstruction technique is preferable because it has been demonstrated that anatomic ligament reconstructions better approximate normal knee biomechanics [6,3]

The purpose of this review is to present anatomical and biomechanical background for anteromedial rotatory instability including surgical management strategies and clinical outcomes of different surgical techniques.

Anatomical and biomechanical background for anteromedial rotatory instability

Anatomy

The primary structures involved in medial knee stabilization are the sMCL, the POL and the deep medial collateral ligament. [19] (Figure 1)

The sMCL, also named the tibial collateral ligament, is the largest structure of the medial aspect of the knee. This structure has one femoral and two tibial attachments. The femoral attachment is oval and is on average 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle. Distally the sMCL has two tibial attachments. The proximal tibial attachment of is a soft tissue attachment over the termination of the anterior arm of the semimembranosus tendon located 12 mm distal to the tibial joint line. The distal tibial attachment has a broad attachment directly to bone at an average of 61 mm distal to the tibial joint line located just anterior to the posteromedial crest of the tibia. The POL is a fibrous extension off the distal aspect of the semimembranosus, which blends with and reinforces the posteromedial joint capsule (Figure 1). It consists of three facial attachments at the knee joint, with the most important portion being the central arm. On average, the central arm of the POL attaches on the femur 7.7 mm distal and 2.9 mm anterior to the gastrocnemius tubercle. The sMCL and the POL are separate structures.[19]

The deep medial collateral ligament is comprised of the thickened medial joint capsule, which is deep to the sMCL. It is divided into meniscofemoral and meniscotibial components (Figure 1B). The meniscofemoral ligament portion has an attachment 12 mm distal and deep to the sMCL's femoral attachment. The meniscotibial ligament, much shorter and thicker than the meniscofemoral ligament portion, attaches just distal to the edge of the articular cartilage of the medial tibial plateau, which is 3 mm distal to the medial joint line, and 9 mm proximal to the proximal tibial attachment of the sMCL.[19]

Injury classifications

The grading of medial knee ligament injuries can be performed by physical examination and imaging. For the standard MCL examination a valgus load at between 20 to 30 degrees of knee flexion is applied with the patient in prone or supine position. The medial joint opening (joint line gapping) is estimated or measured and the noninjured contralateral side is used as a baseline for comparison. In patients with acute injuries or who have sustained pain leading to guarding, performance of a valgus stress test or valgus stress radiograph may underestimate the amount of medial knee laxity.

The most widely utilized medial knee injury grading scale is the American Medical Association Standard Nomenclature of Athletic Injuries in which medial collateral injuries are graded from I to III. [37] Grade I or first-degree tear, present with localized tenderness and no laxity. Grade II or second-degree tears, present with broadened tenderness and an increased joint gapping. This represents partially torn medial collateral and posterior oblique fibers. Grade III or third-degree tears, with a clear laxity without any resistance to an applied valgus stress. Grade III injury represents a complete disruption of all medial structures.

Isolated medial knee injuries have also been classified in accordance to the amount of laxity observed at 30° of knee flexion with a valgus applied moment. These are Grade 1+, 2+, and 3+, which have been reported to correspond to 3-5 mm, 6-10 mm, and greater than 10 mm of subjective medial joint line gapping laxity respectively when compared to the noninjured contralateral side.[12] There is no consensus of which clinical grading system is the best. Research is needed to determine which clinical grading system that optimally detects MCL tissue injury and biomechanics.

<u>Biomechanical properties of the medial ligamentous structures</u>

The posteromedial corner (PMC) has been shown to serve as a restraint to AMRI throughout the normal range of motion.[29] The PMC is functionally composed of 5 anatomic structures: the posterior horn of the medial meniscus, the posterior oblique ligament (POL), the semimembranosus expansions, the meniscotibial (coronary) ligaments, and the oblique popliteal ligament. [29]

A biomechanical study has evaluated the impact of anatomical reconstruction of the MCL and posteromedial corner on valgus and rotatory stability. [9] Ten cadaveric knees were tested in the intact, sMCL and posterior oblique ligament sectioned, and anatomically reconstructed states. The anatomical reconstruction technique involved single tendon strand reconstruction of the superficial MCL and POL with interference screw fixation at their anatomical femoral and tibial insertion sites. The reconstruction was supplied with an anchor fixation at the proximal tibial insertion of the superficial MCL. (Figure 2) Each knee was tested at 0, 20, 30, 60, and 90 degrees of knee flexion with a 10 Nm valgus load, 5 Nm external and internal rotation torques, and 88 N anterior and posterior drawer loads. A six-degree-of-freedom electromagnetic motion tracking system was used to measure angulation and displacement changes of the tibia with respect to the femur. The study found a significant increase in valgus angulation and external rotation after sectioning the medial knee structures at all tested knee flexion angles. This was recovered following the anatomical medial knee reconstruction. A significant increase in anterior translation was observed after sectioning the medial knee structures at 20, 30, 60, and 90 degrees of knee flexion, and this was recovered following MCL reconstruction afor 20 and 30 degrees of knee flexion. The study concluded that an anatomic medial knee reconstruction could restore pre-injured stability to a knee with a complete sMCL and posterior oblique ligament injury, while avoiding overconstraining the reconstructed ligament grafts. Another study by Petersen et al. tested the importance of the POL in PCL deficient knees. In their study sectioning of the sMCL and deep MCL did not increase posterior instability, whereas sectioning of the POL resulted in significant inscreased posterior instability. [27]

Clinical evaluation of anteromedial instability

Examination of the superficial MCL is performed by valgus stress tests, which should be performed at both 0 and 20-30 degrees of flexion. As mentioned above numerous injury classification systems exist to characterized different degrees of superficial MCL insufficiency. With the American Medical Association Standard Nomenclature of Athletic Injuries for grades I-III. [37] Grade I injury has no valgus gapping, grade II, has clearly increased medial joint gapping but with a clear endpoint. Grade III, has clear laxity without any endpoint to an applied valgus stress. Isolated medial knee injuries have also been classified in accordance to the amount of laxity observed at 30° of knee flexion with a valgus applied moment. These are Grade 1+, 2+, and 3+, which have been reported to correspond to 3-5 mm, 6-10 mm, and greater than 10 mm of subjective medial joint line gapping laxity respectively when compared to the noninjured contralateral side.[12]
A finding of valgus laxity at 0 degrees indicates a concomitant cruciate ligament injury[34] but can also represent an injury and laxity of the posteromedial structures including the POL.

Stress radiography

Valgus stress radiographs can be useful for quantitative grading of medial knee instability and to identify the insufficient structures that result in the medial compartment gapping. One study reported that compared to the intact knee, medial joint gapping increases of 1.7 mm and 3.2 mm were produced at 0° and 20° flexion, respectively, by a clinician-applied load when isolated grade III superficial MCL injury was present. A complete medial knee injury involving sectioning of the superficial and deep MCL and POL resulted in gapping increases of 6.5 mm and 9.8 mm at 0° and 20°, respectively.[18]

Anteromedial instability and posteromedial injury assessment (Table 1)

Anteromedial instability is characterized by combined lesion of the superficial MCL and POL and the posteromedial capsule. The anteromedial drawer test and the dial test can evaluate this combined lesion.

The anteromedial drawer test, is performed by flexing the knee to approximately 90 degrees while externally rotating the foot 10 to 15 degrees and applying an anteromedial rotational force to the knee. An anteromedial tibial plateau subluxation is a positive test and is indicative of POL and posteromedial capsule injury.

It has also been reported that a complete injury to the medial structures will cause increased external rotation at both 30 and 90 degrees of knee flexion resulting in a positive Dial test.[32] However it is important to palpate the tibial plateau in relation to the femoral condyle while performing the dial test. If the tibial plateau performs an anteromedial subluxation it is indicative of anteromedial instability whereas a posterolateral subluxation is a sign of posterolateral instability. [23]

Non-operative management of MCL lesions

Treatment for isolated, incomplete injuries grade I and II injuries to the MCL complex is nonoperative. Grade 1 injuries can be managed without any brace with initial RICE treatment and subsequent return to activities within levels of pain. For grade 2 injuries, rehabilitation protocols is typically 4-6 weeks in a hinged brace with free range of motion. This allows for protection against valgus loading and provides normal biomechanical loading pattern through range of motion, which will stimulate proper alignment of ligament healing tissue. [24] Isolated grade 3 injuries can also be managed with similar non-operative strategies but in cause of combined medial a cruciate ligament injuries acute medial repair can be considered. [33] However there is sill significant controversy concerning the indications for acute operative repair for MCL complex injuries.

MCL repair techniques

Operative techniques which have been reported for acute direct repair of the superficial medial collateral ligament and posterior oblique ligament are numerous: such as primary repair with augmentation, advancement of the superficial medial collateral ligament tibial insertion site, pes anserinus transfer, advancement of the superficial medial collateral ligament with pes anserinus transfer. [33] As there is very little literature to define the indication for acute repair treatment, it is beyond the scope of the review paper to present

all these possible surgical techniques.
However, in the setting of combined grade III MCL and bicruciate injuries, a more aggressive approach with repair or reconstruction of all lax structures can be considered. Oslo paper. Another acute setting where repair should be considered is when the superficial MCL is torn from its tibial insertion and become displaced outside the pes anserinus tendons. Here the ligament is unable to reattach to its insertion on the tibia with insufficient healing and increased risk of chronic instability as a result. [24]
Also tibial-sided injuries to the meniscal attachment to the deep MCL and posteromedial capsule can be considers restored by placing suture anchors along the peripheral rim of the tibia and bringing them through the deep MCL. [16]

Anatomical MCL reconstruction techniques

Medial knee ligament reconstruction techniques that address both the superficial MCL and the posterior oblique ligament have only been described in few studies. In this section the main surgical techniques are described including the clinical data supporting the techniques. These techniques use hamstring tendon autografts. However other MCL reconstruction techniques has been described using allografts or autografts for typically isolated reconstruction of the superficial MCL. [1,25]

<u>LaPrade-Engebretsen MCL reconstruction technique (Figure 2).</u>

This anatomic technique consists of a reconstruction of the sMCL and posterior oblique ligament using two separate grafts with four reconstruction tunnels. [21] The approach can be performed with either one large medial knee incision or by using three smaller medial knee incisions to access the anatomic attachment points of the ligaments. The most proximal incision is made vertically along the medial knee and parallel to the long axis of the femur, essentially in line with the distal adductor magnus tendon, and measured a total of six cm in length. The distal end of this incision is located one cm proximal to the joint line, and the incision is placed five cm posteromedial to the medial border of the patella. Then the femoral anatomic attachment points of the superficial MCL and POL are exposed by blunt dissection. The two distal incisions are also vertical and parallel to the long axis of the leg. With a 5 cm anteromedial incision the tibial insertion of the sMCL is exposed. The sartorius muscle fascia is then incised and the gracilis and semitendinosus tendons were exposed. The semitendinosus is then harvested using a hamstring stripper and sectioned into two parts, one measuring 16 cm for subsequent sMCL reconstruction and the other 12 cm for subsequent POL reconstruction. Each portion of the tendon is tubularized on both ends using No. 2 nonabsorbable sutures to fit into 7 mm tunnels. Alternatively, allograft tendon may be used.

Attention is turned to the distal tibial attachment of the superficial MCL, approximately six cm distal to the joint line. The third and final incision is placed along the posteromedial border of the proximal tibia and allowed access to the tibial insertion of the POL (Figure

2). This incision is two cm posterior to the posteromedial crest of the tibia and is five cm long. The most proximal edge of this incision is located one cm proximal to the joint line. Careful dissection is performed to identify the sartorial branch of the saphenous nerve through this incision. To protect the sartorial branch of the saphenous nerve, which usually courses posterior to the sartorius muscle belly and tendon at this level, the fascia anterior to the sartorius muscle tendon is incised, and the sartorius tendon is retracted distally. At this point, the attachment site of the central arm of the POL is identified at the posteromedial tibia near the direct arm of the semimembranosus tendon. After isolating the attachment locations of the superficial medial collateral and posterior oblique ligaments, attention is returned to drilling the reconstruction tunnels. Using an eyelet pin 7 diameter and 30 mm deep sockets are drilled at the femoral attachment of the sMCL and the posterior oblique ligament. The 16 cm and 12 cm sections of semitendinosus tendon that was previously tubularized are then passed into the tunnels and using an eyelet pin, and is recessed 25 mm into the tunnel and fixed with 7 mm cannulated bioabsorbable screws.

The tibial tunnels for the distal sMCL and posterior oblique ligament anatomic attachment points are reamed in similar fashion next. The distal superficial MCL tunnel is reamed first through the center of the distal superficial MCL anatomic attachment point located 6 cm distal to the joint line. Next, an eyelet pin is drilled through the center of the tibial attachment of the central arm of the POL, which exited just distal and medial to Gerdy's tubercle. A 7 x 30 mm socket is reamed. The superficial MCL graft is then passed under the fascia to the distal superficial MCL tunnel recessed to a depth of 25 mm. The knee is placed in 30 degrees of knee flexion, in neutral rotation, and a varus force is applied to reduce any gapping of the medial compartment. The superficial MCL reconstruction graft is then tensioned and secured in place with a 7 mm bioabsorbable screw at the distal aperture of the tunnel. The knee is then placed through a full passive range of motion to verify proper positioning of the superficial MCL graft. The proximal tibial attachment point of the superficial MCL, which is primarily to soft tissues and located just distal to the joint line is recreated by suturing the sMCL graft to the anterior arm of the semimembranosus muscle with a suture anchor. Finally, the POL graft is passed into the tibial tunnel and recessed. The graft is tensioned secured with a 7 mm bioabsorbable screw

Clinical outcome LaPrade-Engebretsen technique

A case series of 28 patients (19 male, nine females) was operated between 2007 and 2009. The average age was 32.4 years (range, 16-56 years). There were eight acute and 20 chronic injuries. All patients presented with subjective and objective valgus instability limiting activities of daily living and sports activities. Minimum follow-up was 6 months (average, 1.5 years; range, 0.5-3 years). It was found that subjective outcome evaluated by International Knee Documentation Committee (IKDC) subjective outcome scores improved from preoperative 43.5 (range, 14-66) to final postoperative values of 76.2 (range, 54-88). Preoperative valgus stress radiographs averaged 6.2 mm of medial compartment gapping compared with the contralateral normal knee, whereas postoperative stress radiographs averaged 1.3 mm. [21]

Lind MCL reconstruction technique (Figure 3)

This anatomic MCL reconstruction technique consists of a reconstruction of the sMCL and posterior oblique ligament using the semitendinosus tendon placed in one femoral tunnel and two tibial tunnels. [22] The approach can be performed with either one large medial knee incision or by using three smaller medial knee incisions to access the anatomic attachment points of the ligaments. The semitendinosus tendon is harvested at the pes anserinus and the insertion at pes anserinus is kept intact. The medial femoral epicondyle is exposed through a longitudinal incision. The femoral MCL insertion site is identified just posterior to the medial epicondyle and anterior to adductor tubercle. An eyelet pin K-wire is drilled in the proximal center of femoral MCL insertion. An 8 X 30 mm tunnel is drilled sized according to the measured diameter of the double looped tendon. Now the released semitendinosus tendon is pulled along the K-wire and folded to create a tendon loop that will enable the loop to be recessed 25 mm into the femoral drillhole and fitted with No 2 Fiberwire baseball suture. The semitendinosus tendon is then passed under the fascia to the femoral drill tunnel. The sutured loop is then passed into the tunnel with pull-through technique and fixed with an 8 x 25 interference screw to reconstruct the superficial MCL. The reconstruction is tightened at 10 degrees of flexion and neutral rotation. The non-fixated free end of the tendon is now used to for the posterior oblique ligament reconstruction. A tibial tunnel is then drilled at the posterior corner of the medial tibial condyle just proximal to tibial insertion of semimembranosus tendon. Tunnel diameter is the size of semitendinosus graft, which typically was 6 mm. The free end of graft is passed under the fascia from the femoral condyle to the tibial posterior oblique ligament tunnel. The graft is tensioned at 10 degrees of flexion and fixed with an interference screw with the same diameter as the drill tunnel to reconstruct the posteromedial corner. The reconstruction will appear as an inverted V on the medial aspect of the knee. (Figure 2)

Clinical outcome Lind technique

In a case series 61 patients with grade 3 or 4 medial instability were treated with MCL reconstruction. Thirteen patients had isolated MCL reconstructions, 34 were combined with ACL reconstruction and 14 were multiple ligament reconstructions. All had reconstruction of the medial collateral and the POL with a semitendinosus autograft. Fifty patients were available for follow-up more than 24 months post-operatively and were examined by an independent observer using objective IKDC measures and subjective Knee Osteoarthritis Outcome Score (KOOS). Objective IKDC medial stability at follow-up was in 98 % of patients normal or nearly normal (grade A or B). The overall objective IKDC score patients improved from 5 % grade A or B preoperatively to 74 %. Ninety-one percent were satisfied or very satisfied with the result and 88% would go through surgery again. KOOS score improved primarily for sports and quality of life subscales with approximately 10 point improvements. It was concluded that MCL reconstruction with combined collateral and POL reconstruction technique resulted in good clinical outcome in patients suffering from chronic valgus instability. [22]

Discussion

Injuries to the medial collateral ligament comprise one of the most commonly injured ligaments of the knee, and combined MCL and POL injuries are frequently found in patients with valgus laxity about the knee joint. [14] All medial knee injuries with objective medial laxity should be managed by initial functional bracing to ensure optimal spontaneous healing. However, patients with grade 3 medial lesions and/or combined medial and cruciate ligament lesion have increased risk of developing chronic medial instability which may need surgical treatment. [20]

Despite the presence of a high frequency of medial knee injuries, only limited literature presents biomechanically validated anatomic reconstruction techniques. [4] The results from a study by Widjicks et al suggest that an anatomic medial knee reconstruction technique can restore near normal stability to a knee following complete sectioning of the superficial MCL and POL.[36] The anatomical medial knee ligament reconstruction techniques presented in this paper is supported by biomechanical validation and clinical data demonstrating good clinical outcome in a patients with both isolated MCL lesions and combined ligament reconstructions that included MCL reconstruction. This is reflective of the clinical variation of MCL instability patients. [21]

Clinical evaluation of medial knee instability is challenging. Especially the separation of insufficiency of the individual medial structures can be difficult. Anteromedial rotatory instability is characterized by combined superficial MCL and POL instability.

Insufficiency of the superficial MCL is best evaluated by manual valgus examination. This examination can be supplemented by stress-radiography. If the medial gapping of is more than 3 mm an insufficiency of the superficial MCL is present. If stress-radiography demonstrates a medial gapping of more than 6 mm both superficial MCL and the POL is involved. Insufficiency of the POL can further be identified clinically by a positive anteromedial drawer test and positive dial test.

The clinical decision strategy for performing medial knee ligament reconstruction thus optimally relies on combined clinical and imaging evaluation. If substantial valgus instability can be established by clinical valgus examination then this finding should be confirmed by stress radiography. If radiographic valgus laxity is confirmed, then good indications for medial ligament reconstruction exist. If in addition clinical signs of POL

insufficiency exist in the form of positive anteromedial drawer test and dial-test is present, then a surgical reconstruction strategy should include an anatomical reconstruction technique that addresses the superficial MCL as well as POL.
Such reconstruction techniques have been presented previously in this paper. [22,21] There are several surgical considerations that can be made when performing medial ligament reconstructions. If isolated MCL reconstructions are performed, minimal invasive strategies can be considered using three small incisions. Alternatively one large medial incision could be used to approach the all the medial knee structures. We recommend the use of one large incision on obese patients or for more complex surgical cases such as multi-ligament procedures. For combined ACL and MCL instability some surgeons avoid the usage of hamstring tendons for ACL reconstructions with combined MCL instability. The hamstring tendons are dynamic medial stabilizers so in theory preserving the hamstring tendons is beneficial for medial stability. However no clinical studies have demonstrated that hamstring harvest increased objective or subjective medial stability.

In conclusion anteromedial knee instability should be established by combined clinical and radiological evaluation. Management of anteromedial instability in chronic patients should involved reconstruction techniques that address both the superficial MCL and the posteromedial structures including the POL

TABLE 1

Clinical evaluation of anteromedial knee instability.

Legend:

The table presents the clinical findings of both manual examinations and stress radiography in case of isolated superficial MCL lesion and Combined superficial MCL and posteromedial injury. The stress radiography thresholds are based on biomechanical studies from LaPrade et al. (2010) Am J Sports Med 38 (2):330-338.

	Isolated superficial MCL lesion	**Combined superficial MCL and posteromedial injury**
Manual valgus testing 0 degrees	No gapping	Increased gapping
Manual valgus testing 20-30 degrees	Increased gapping without endpoint	Increased gapping without endpoint
Positive anterior drawer test	No	Yes
Positive dial test	No	Yes
Stress radiography 0 degrees	> 1,7 mm	> 6.5 mm
Stress radiography 20-30 degrees	> 3.2 mm	> 9.8 mm

Figure Legends

Figure 1. Illustration of the superficial medial collateral ligament (sMCL) (medial aspect, left knee), and posterior oblique ligament (POL) (reprinted with permission from The Journal of Bone Joint Surgery, 2007; 89(9): 2004, figure 4).

Figure 2 A right medial knee reconstruction procedure demonstrating the reconstructed sMCL and POL using two separate reconstruction strands with separate drill holdes. Note that the proximal tibial attachment point of the sMCL, which was primarily to soft tissues and located just distal to the joint line, was recreated by anchor suturing the sMCL graft to the anterior arm of the semimembranosus muscle. Reprinted with permission from The American Sports Medicine, 2010; 38(6): 1116-22, figure 1).

Figure 3 Medial knee reconstruction technique with combined sMCL and POL reconstruction using a single femoral fixation point. The semitendinosus tendon is released and the pes anserinus insertion retained. The tendon is looped into a drill hole in the medial femoral condyle. The free strand of the tendon is passed from posterior into a drill hole in the medial tibial condyle. (Reprinted with permission from The American Sports Medicine, 2009; 37(6): 1116-22, figure 1).

Figure 1

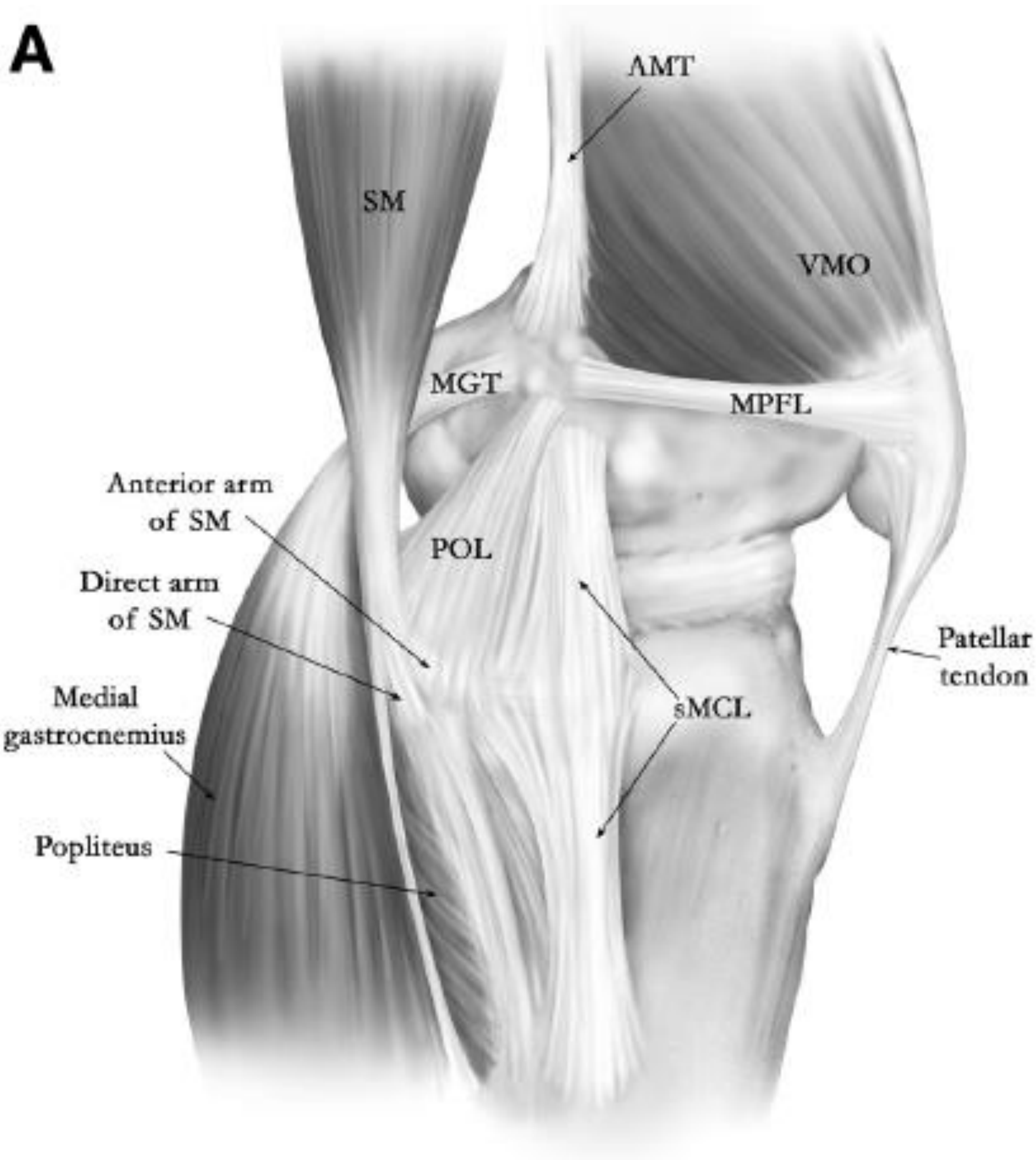

A
AMT
SM
VMO
MGT
MPFL
Anterior arm of SM
POL
Direct arm of SM
Patellar tendon
Medial gastrocnemius
sMCL
Popliteus

Figure 2

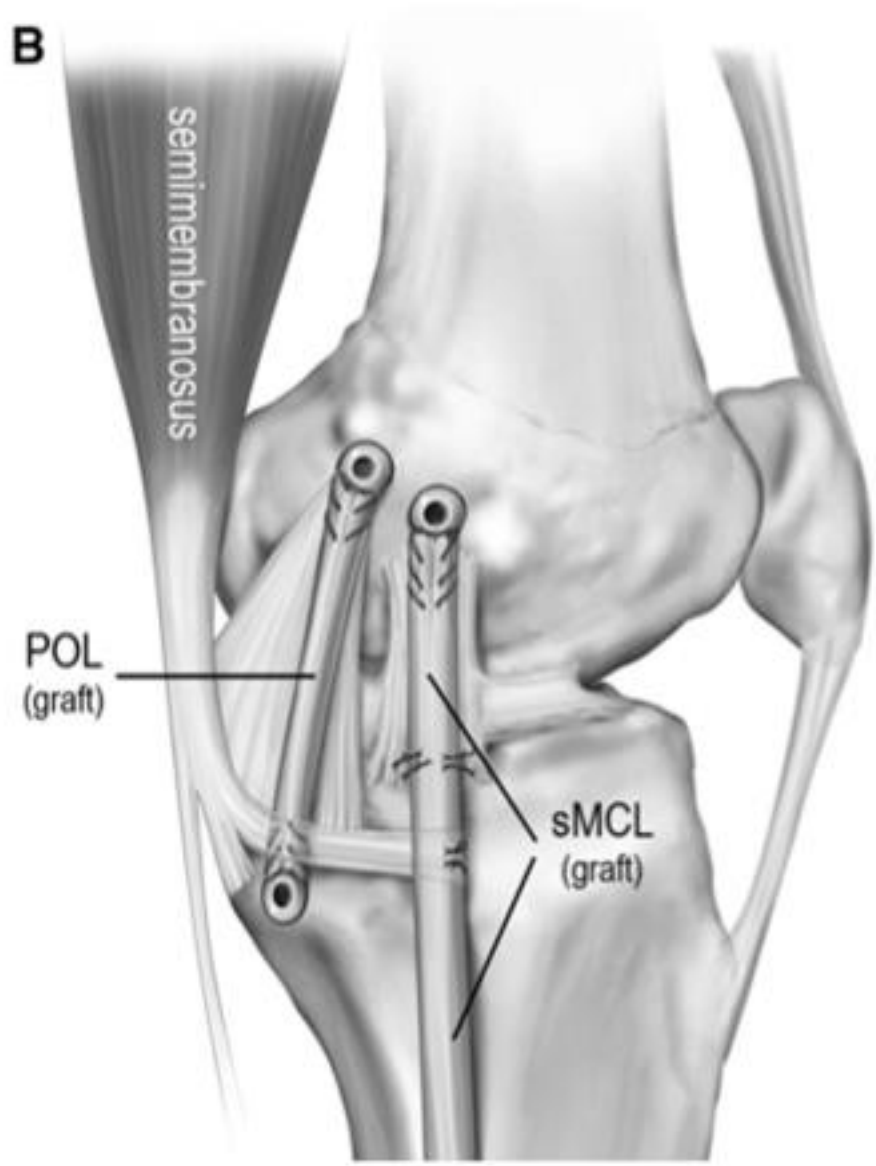
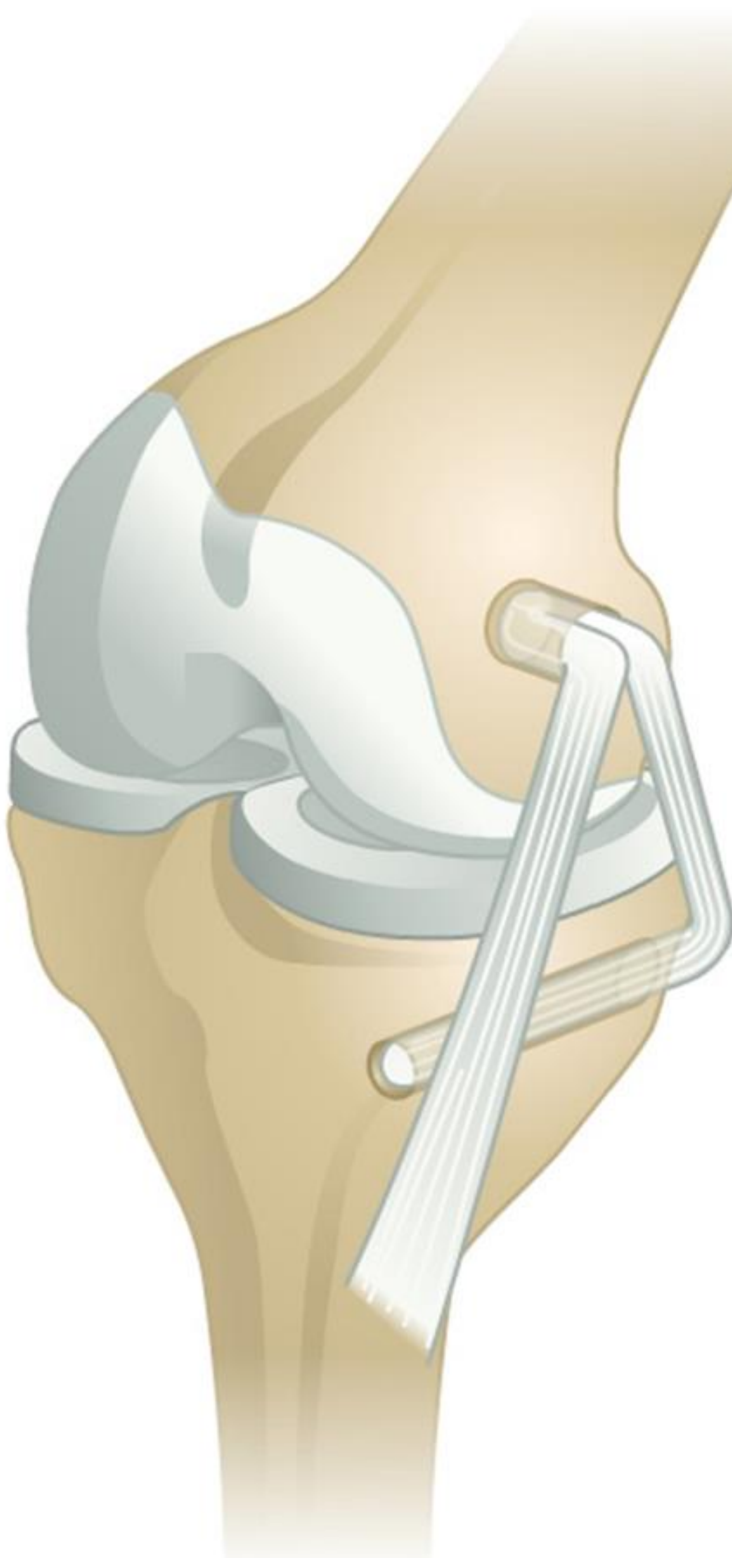


Figure 3



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