An Updated Overview of the Anatomy and Function of the Proximal Medial Patellar Restraints (Medial Patellofemoral Ligament and the Medial Quadriceps Tendon Femoral Ligament)

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Abstract: The medial patellofemoral ligament (MPFL) has been widely accepted to function as "the primary static restraint to lateral patellar displacement." However, current growing evidence suggests that there is a complex of medial patellofemoral/tibial ligaments, both proximal [MPFL, and medial quadriceps tendon femoral ligament (MQTFL)], and distal (medial patellotibial ligament and the medial patellomeniscal ligament) which restrain lateral patellar translation at different degrees of knee flexion. Specifically, the MQTFL has gained popularity over the last decade because of pure soft tissue attachments into the extensor mechanism that allow for avoidance of drilling tunnels into the patella during reconstruction. The purpose of this article was to report on the current knowledge (anatomy, biomechanics, diagnosis, indications for surgery, and techniques) on the proximal medial patellar restraints, namely the MPFL and the MQTFL, collectively referred to as the proximal medial patellar restraints.

Key Words: medial patellofemoral ligament, medial quadriceps tendon femoral ligament, patellar instability, reconstruction, patellofemoral joint restraints, soft tissue, stabilizers

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Lateral patellar dislocations have been reported to be the second leading cause of traumatic knee hemarthroses and therefore constitute an important burden to the health care system.[1] The medial knee structures (Fig. 1) responsible for stabilization of the patellofemoral joint are currently identified as the proximal medial patellar restraints (PMPR), which includes the medial patellofemoral ligament (MPFL) and medial quadriceps tendon femoral ligament (MQTFL). Despite having been called the primary static stabilizer to the patella, the MPFL has been reported to account for approximately half of the total restraint to lateral patellar displacement.[1–6] In this regard, a recent study[5] evaluated the medial patellar stabilizers at different degrees of flexion, reporting the MPFL to be the primary medial stabilizer of the patella in the first 30 degrees of flexion, whereas the distal stabilizers [medial patellotibial ligament (MPTL) and medial patellomeniscal ligament (MPML)] have an increased role in restriction of lateral translation, patellar tilt and patellar rotation at higher degrees of flexion.[5]

Altered patellofemoral joint contact forces, patellar instability, and joint degeneration are some of the potential consequences of injury to this complex,[7,8] which emphasizes the importance of an appropriate and timely treatment of this pathology to restore joint kinematics. Conservative management of lateral patellar dislocations has been reported to be associated with recurrent dislocations in up to 35% of patients, which highlights the importance of proper patient selection for conservative approaches [it should be avoided in patients with significant bony abnormalities such a trochlear dysplasia (type D), patella alta, and younger individuals].[9–11] In the setting of recurrent lateral patellar instability, a surgical approach is typically recommended, including a medial soft tissue reconstruction with adjuvant bony and soft tissue procedures depending on associated anatomic instability factors.[12–14] However, it is worth noting that a vast number of surgical procedures[7,15] aiming at restoring patellar stability developed in recent years make it difficult to decide the best course of treatment, thus rendering comprehensive anatomic and biomechanical knowledge increasingly meaningful in a surgeon's day-to-day practice. The purpose of this article is to report on the current knowledge (anatomy, biomechanics, diagnosis, indications for surgery, and

FIGURE 1. A dissected fresh-frozen knee specimen outlining the key anteromedial knee structures. 1, Medial patellofemoral complex (proximal medial patellar restraints); 2, medial epicondyle, medial collateral ligament; 3, adductor magnus tendon; 4, vastus medialis obliquus; 5, patella; 6, patellar tendon; 7, oblique fibers of the proximal medial patellar restraints. full color online

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techniques) regarding the proximal medial patellar restraints, namely the MPFL and the MQTFL, collectively referred to as the PMPR.

FIRST DESCRIPTIONS AND CURRENT ANATOMIC QUANTITATIVE DATA ON THE MEDIAL PATELLOFEMORAL COMPLEX

Warren and Marshall[8] first described the "patellofemoral ligament" which was located in layer II after dissecting 154 cadaveric specimens in 1979. They delineated a condensation of fibers extending from the medial epicondyle to the superomedial aspect of the patella. It was not until 1993,[2] that an additional attachment on the undersurface of the distal aspect of the quadriceps mechanism was reported. Novel dissection techniques paired with quantitative anatomic data have significantly expanded on the anatomic characteristics of the PMPR.

Of note, most of the efforts to quantify the anatomy were originally geared to the femoral origin to attempt to replicate its attachment during reconstruction procedures because it was reported that any modification of the attachment point substantially influenced the relative length and the dynamic length change of the grafts during knee flexion and extension.[16,17] The PMPR origin on the femur has been consistently identified to be located between the adductor tubercle and medial epicondyle.[1,2,12,18] More precisely, a recent literature review concluded that over the last 2 decades of anatomic studies, the femoral attachment on the adductor tubercle was found in 29.6% of cases, whereas in 17.8% of cases the attachment was located somewhat on the medial epicondyle. Yet still, 44% of all reported cases point to other attachment sites.[19]

A quantitative study reported that the PMPR femoral origin was 9.6 mm anterodistal to the adductor tubercle and 15.2 mm proximal and posterior to the medial epicondyle.[20] Qualitatively, fibrous attachments to the adductor tendon and tubercle were also identified in a consistent basis originating from the femoral origin of the PMPR.[21] The mean area of the attachment on the distal femur is 26 mm,[1,21] demonstrating the minuscule nature of the ligament (Fig. 2) which is often replaced by significantly more robust grafts during reconstruction.

Radiographic identification of the PMPR femoral origin has been extensively described in the literature.[20,22–25] Nevertheless, anatomic accuracy of the femoral attachment point identified by radiographs is less than optimal, as radiographic positioning 5 degrees off-axis from a true lateral radiograph has a significant effect on the radiographic positioning of the femoral tunnel. Therefore it should only be used to confirm the anatomic findings encountered during the surgical exposure.[21] Sanchis-Alfonso et al,[26] Ziegler et al[24] have emphasized the limited utility of radiographic criteria. Generally, the femoral origin of the PMPR lies 8.3 mm anterior to the posterior cortex extension line, and 4.7 mm proximal to the level of the posterior point of Blumensaat's line on lateral radiographs.[20] The most commonly used method for its simplicity, and not necessarily for its accuracy, is the one described by Schöttle et al,[27] who described the mean point of the femoral origin as 1 mm anterior to the posterior cortical line, 2.5 mm distal to the proximal origin of the medial femoral condyle, and proximal to the posterior aspect of Blumensaat's line.

From this origin, the PMPR diverges medially and proximally (mean length is 56 mm) deep to the vastus medialis obliquus (VMO) (Fig. 3) to attach broadly to the deep VMO tendon (through a fascial attachment), the proximal third of the patella (MPFL) and to the deep layer of the quadriceps tendon (MQTFL).[20] Previous evidence described the presence of fibers extending to the quadriceps tendon.[2,21,28] Two different groups reported on an attachment to the undersurface of the vastus medialis in 100% of knees and to the superomedial patella in 88% of knees.[28,29] In addition, the authors described that some fibers extended to the quadriceps tendon in 48% of knees[28] (Fig. 4).

In addition, Mochizuki et al[30] described the attachments of the PMPR to the deep intermedius tendon in 2013, which is consistent with Ge's findings.[21] Fulkerson et al[14] first termed these proximal "discrete" fibers to the quadriceps tendon as the MQTFL, and this has been described by others in more recent studies.[20] Tanaka et al[31] reported on 28 cadaveric knees, that some fibers attached to the patella (57.3%) and the remainder attached to the quadriceps tendon. The Tanaka group then defined an anatomic midpoint of the PMPR which was located at the 2.3% of the articular length distal to the superior pole of the patella)[32] taking into account both the MPFL and the MQTFL components of the proximal PMPR Furthermore, significant variations in the PMPR attachments were identified by these authors, with 1 knee exhibiting 100% of fibers

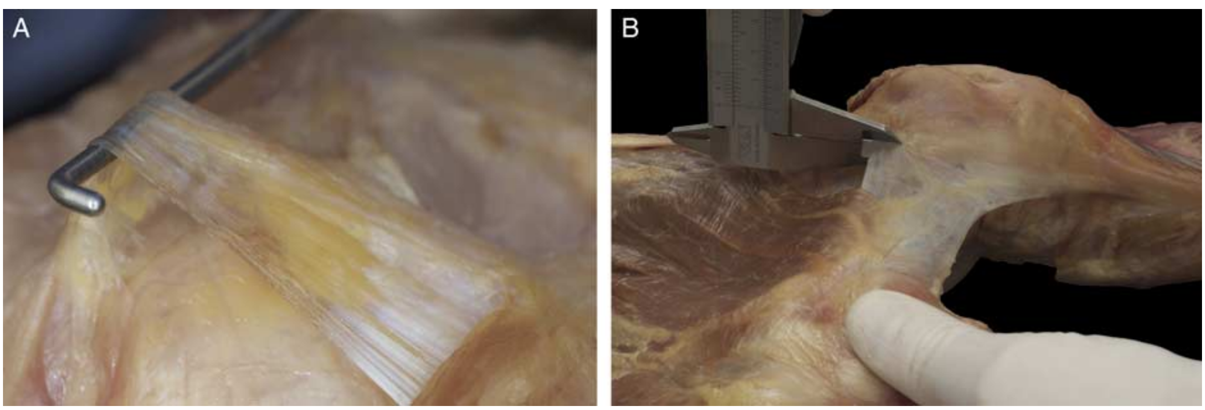

FIGURE 2. The miniscule nature of the medial patellofemoral ligament (proximal medial patellar restraints) origin. A, A picture showcasing the fibrous structure of the proximal medial patellar restraints origin on the distal femur. B, The thickness measurement using a Vernier caliper highlights the thinness of the structure. full color online

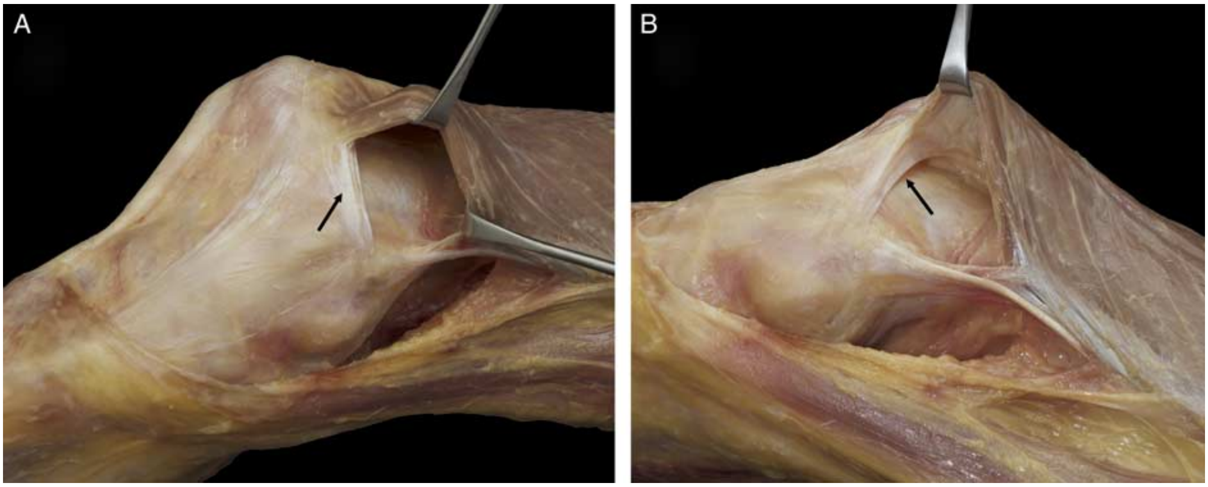

FIGURE 3. An outside-in view on the medial patellofemoral complex (proximal medial patellar restraints) diverging medially and proximally deep to the vastus medialis oblique. A, The fibers of the upper portion of the proximal medial patellar restraints running into the deep layer of the vastus medialis obliquus (arrow). B, proximal medial patellar restraints fibers running under the muscle and attaching to the deep layer of the quadriceps tendon (medial quadriceps tendon femoral ligament) (arrow).

attaching on the patella and another with a sole attachment to the quadriceps tendon, which may explain the variations in anatomic reports that describe this ligament. In this regard, Kang et al,[33] although others could not recognize such division, described PMPR fibers as 2 separate bundles, with the inferior-straight bundle attaching to the patella and the superior-oblique fibers attaching to the quadriceps tendon. They reported a mean of 25.1 ± 2.1-degree angle between these 2 bundles. Another quantitative anatomic study,[20] reported the presence of the MQTFL in 100% of the specimens, with a mean insertion length of 29.3 mm on the medial aspect of the distal quadriceps tendon. Finally, in addition to the insertion onto the quadriceps tendon, an attachment to the VMO has been described.[2,6,29,31,34]

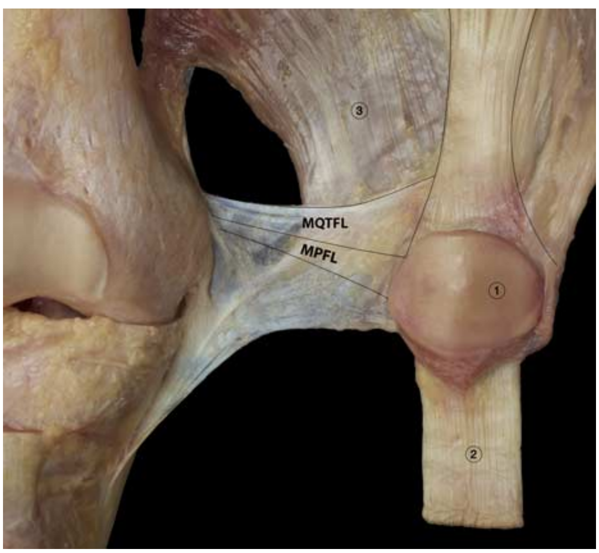

FIGURE 4. Medial patellofemoral complex (proximal medial patellar restraints) shown from the inside view—key landmarks were indicated: patella (1), patellar tendon (2), vastus medialis obliquus (3). MPFL indicates medial patellofemoral ligament; MQTFL, medial quadriceps tendon femoral ligament. full color online

The most recent cadaveric study by Ge et al[21] provides a unique insight into the MPFL's structure since the researchers utilized 2 different dissection techniques and arrived at a conclusion that the MPFL has a complex polygon-shaped structure. The outside-in dissection (the commonly used method) revealed the upper portion of the MPFL consisting of transverse fibers with a bony femoral origin with the mean length of 62.7 ± 5.2 mm, width of 7.5 ± 1.1 mm, and thickness of 0.4 ± 0.1 mm; and the lower portion going downward to the superficial layer of the medial collateral ligament and presenting as a triangular structure. From this view, the superficial fibers stemming from the attachment on the femur extended to the adductor magnus tendon in most of the knees, whereas in 12 of 16 cases they extended to the medial gastrocnemius tendon. The inside-out technique, on the other hand, revealed that the fibers of the MPFL radiate to the bony edge of the patella with a wide attachment consisting of 2 parts: a bony 1 with a mean width of 16.3 ± 3.8 mm, occupying the entire bony attachment of the VMO and running further to the edge of the patella; and the superiorly directed nonbony part attached to the vastus intermedius tendon with a mean width of 21.7 ± 4.8 mm. The length of the ligament measured from this view was 67.9 ± 6.1 mm on average. On the basis of the recent studies it can be said that the MPFL has ample connections to the surrounding tissues, including the VMO and quadriceps tendon, thus making it both static as well as a dynamic structure.

BIOMECHANICS OF THE MEDIAL PATELLOFEMORAL COMPLEX

Although the MPFL has been called the main medial patellar restraint, new evidence suggests that the MPTL, MPML, and MQTFL also play important roles in medial patellar stability.[1,8] In this regard, the biomechanical characteristics and precise dynamic function of the PMPR (MPFL and/or MQTFL) have yet to be fully determined. Limited data on this topic highlights the difficulties and limitations of replicating the in vivo mechanics and forces in a cadaveric setting. For this reason, the majority of studies performed have utilized straight lateral translation of the patella,[6,11,12] without taking into consideration the probable superolateral forces on the patella in vivo.

Dynamically, the largest change in PMPR strain has been reported to occur at 30 degrees of flexion as the patella engages with the trochlea.[35] As such, transection of the PMPR results in maltracking with lateral translation and increased lateral trochlea contact pressures. After 60 degrees of knee flexion, lateral patellar translation is usually prevented by trochlear engagement (fixed curvature), and the force required to displace the patella is independent of damage or reconstruction of the PMPR.[35]

A recent study[36] evaluated the biomechanical characteristics of each individual ligament.[5] The "MPFL" mean failure load was identified to be 178 N, which is similar to the results published by Burks et al, Criscenti et al, Herbort et al, and Mountney et al studies.[37–40] The mean failure load of the MPTL and MPML were 147 and 105 N respectively, suggesting that they could potentially have a significant functional role in stabilizing the patella against superolateral translation. Importantly, there was a relatively low stiffness of all the medial sided patellar ligaments which suggests a certain degree of elasticity before failure for the patellofemoral joint, which is especially interesting in the light of the fact that some of the complex's superficial fibers have been reported to run to the medial gastrocnemius.[21]

OBJECTIVE DIAGNOSIS OF PATELLOFEMORAL PATHOLOGY

During consideration for PMPR reconstruction, a comprehensive history and physical examination of the patellofemoral joint should be performed in a systematic approach.

Lateral radiographs are useful to assess trochlear morphology and to classify the trochlear shape according to the Dejour classification.[41] In addition, patellar height has been reported to be a risk factor for patellar dislocations. The Caton-Deschamps index is the preferred method to assess patellar height due to its accuracy and ability to remain unaffected by the degree of knee flexion.[42] Axial radiographs with the knee at 30 degrees of flexion allow for an approximate assessment of the sulcus angle and the depth of the trochlear groove.[43] A sulcus angle of $\geq$145 degrees has been reported to represent a dysplastic trochlea,[44] although it is best characterized utilizing a combination of quantitative radiographic measurements and the Dejour classification system.

Preoperative computed tomography is one of the most valuable tools to assess the patellofemoral joint with regard to malalignment. A tibial tubercle-trochlear groove (TT-TG) distance $>$20 mm on computed tomography scans is considered to be pathologic and is a substantial risk factor for patellar instability.[40] Nonetheless, recent literature reported that while the TT-TG value might differ based on several factors, such as age, sex, body mass index, and varying degrees of knee flexion on cross-sectional imaging, it remains the most useful measurement for determining the presence of coronal plane patellofemoral joint malalignment.[45] The tibial tubercle-posterior cruciate ligament is a recently described measurement for pure lateralization of the tibial tubercle, and may be used in conjunction with the TT-TG to better understand the path taken by the extensor mechanism during knee range of motion. Lastly, magnetic resonance imaging is helpful to evaluate articular cartilage status[46] and identify soft tissue damage, particularly with regard to PMPR injury. Magnetic resonance imaging is also used to measure lateral trochlear inclination.[47] For this measurement, the most superior axial cut showing trochlear cartilage is chosen. The inclination is the angle formed between the plane of the lateral trochlear facet subchondral bone and a tangential line through the posterior femoral condyles. An angle of <11 degrees is considered abnormal.

SURGICAL TECHNIQUE

Reconstruction of the PMPR may involve recreating the fibers that attach to the patella (MPFL), or quadriceps tendon (MQTFL), or both. For MPFL reconstruction, multiple fixation options exist. In the authors' technique, the patient is placed in the supine position and an anterior midline incision is performed.[48] The MPFL attachment on the patella is then identified, which is ~41% distal to the proximal pole, and an aiming guide is used to drill a guide pin transversely across the dorsal cortex of the patella. At this point, it is important to be cautious not to violate the dorsal cortex as this can increase the risk of fracture. A cannulated 4.5-mm reamer is used to create a tunnel to pass a cortical button fixation device. Then a 5-mm reamer is utilized to form an 8- to 10-mm deep socket for the graft, and the remaining tunnel length is measured. The course of the MPFL is followed along the distal edge of the VMO with sharp dissection medially, and the adductor magnus tendon is identified. Using the adductor magnus tendon as a landmark, the adductor tubercle and medial epicondyle are identified. The femoral origin of the MPFL is located at a point 1.9 mm anterior and 3.8 mm distal to the adductor tubercle[29] and 2 suture anchors are placed in this location. The semitendinosus graft is identified and released of all adhesions and harvested with an open tendon stripper. The graft is then tubularized and attached to a cortical fixation device prepared on the back table. The graft should have a minimum length of 16 cm.

Next, a passing suture is placed through the patellar tunnel and used to pull the MPFL graft into the patellar socket and then secured to the dorsal surface of the lateral patella with a cortical fixation device. The graft is then passed transversely across the previously created channel along the normal course of the native MPFL, deep to the superficial layer of the medial retinaculum, just distal to the VMO. With the knee in 60 degrees of knee flexion and the patella in a neutral position in the trochlea, the graft is tied to the suture anchors at the femoral attachment with care not to place tension on the graft. MPFL graft fixation at $\geq$60 degrees of knee flexion has been reported to result in fewer complications and recurrent instability compared with fixation in less flexion.[49] In other words, the key is setting the length at the degree of flexion at which the attachment sites are farthest apart so the graft will become more lax at other degrees of flexion.

Alternatively, or in addition to the MPFL component reconstruction, the MQTFL may be reconstructed. In this case, the tendon graft is secured on the femur and brought through a 1.5 cm incision along the VMO incision at the proximal third of the patella and then down through a second longitudinal incision in the quadriceps tendon. Then the knee is cycled to establish optimal attachment of the PMPR graft to the quadriceps tendon.[14]

During the graft tensioning and fixation process, the patella is positioned a few millimeters laterally to avoid over medialization. After the graft has several sutures in place,

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the patella is tested with lateral translation at varying degrees of knee flexion to confirm restoration of an adequate restraint to lateral translation without overtightening medially. At 20 degrees of knee flexion, the surgeon should be able to lateralize the patella 1 to 2 quadrants with a gentle pressure applied to the medial facet. Once this is confirmed, the remaining sutures are secured. The arthrotomy is copiously irrigated and closed. Steristrips and a sterile dressing are placed over the incision, and the knee is placed in an immobilizer.

After the surgery, patients are allowed weight-bearing as tolerated and in an immobilizer brace for 6 weeks with full active range of motion as tolerated. A supervised rehabilitation program should start immediately postoperatively using the periodization concept (range of motion, muscular endurance, strength, and power phases to be developed based on the patients return to play timelines). Quadriceps exercises, straight-leg raises, and ankle-pumps with the patient wearing a knee immobilizer should be performed 3 to 5 times daily. Passive range of motion should be limited from 0 to 90 degrees of flexion for the first 2 weeks and then increased as tolerated. Return to normal levels of activity typically occurs after 6 to 9 months postoperatively.

OUTCOMES OF PMPR RECONSTRUCTION

Restoring the anatomy of the PMPR during reconstruction is essential to achieve optimal outcomes. However, certain risk factors have been identified, regardless of the reconstruction technique, such as age older than 30 years, female sex, high-grade chondral injury, and obesity which have been reported to affect patient outcomes.[50] Redislocation rates after PMPR reconstruction have been reported to be as low as 4.5%.[50] However, apprehension or sensation of subluxation can occur in up to 11% of cases.[50] To this point, a recent systematic review reported an overall complication rate of 26.1%, with nearly a third of these complications attributed to recurrent apprehension.[49] Additional complications reported were arthrofibrosis, iatrogenic medial instability, patellofemoral degenerative changes and residual pain, patellar fracture, graft failure, wound complications, and implant pain.[49] Of note, more complications were reported in reconstruction techniques using bone tunnels. Conversely, suture fixation techniques were correlated with a higher rate of recurrent instability.[49] Nonetheless, a recent meta-analysis[51] reported that the mean postoperative improvement in the Kujala score after MPFL reconstruction was greater using the suture anchor method than the double transpatellar tunnel method ($P = 0.018$). However, the mean improvement in the Lysholm score did not differ significantly using the 2 techniques.

There is some controversy on whether concomitant pathology should be addressed in addition to reconstructing the PMPR. Steiner et al[52] reported on 34 patients (mean follow-up of 66.5 mo) with varying degrees of trochlear dysplasia in whom only an PMPR reconstruction was performed. The authors reported a mean Kujala score improvement from 53.3 to 90.7. Hiemstra et al[53] suggested that high-grade trochlear dysplasia was associated with worse Banff instrument scores when compared with mildly dysplastic patients treated with isolated MPFL reconstruction or MPFL imbrication (69.91 vs. 60.02). Of note, recurrent instability for isolated PMPR reconstruction in highly dysplastic patients (types C and D) has been reported to be as high as 100% (compared with 7.4% in types A and B). At least 3 previous reports have suggested that the addition of a tibial tubercle transfer to an MPFL reconstruction, does not provide added long-term clinical and radiologic benefits.[54–56] Conversely, a recent randomized study by Damasena et al[57] demonstrated significantly improved patellar tilt and congruence angle measurements for patients treated with PMPR reconstruction and TTO versus TTO alone.

In the only study that reported using a combined MPFL and MPTL reconstruction, 22 patients were evaluated with a mean follow-up of 43 months. This group obtained significant improvement in subjective knee function with minimal risks, although preinjury activity levels were not consistently restored.[58]

CONCLUSIONS

The PMPR is a complex and variable structure with insertion on the proximal patella and distal quadriceps tendon that should be regarded as the main (but not only) restraint in lateral patellar translation. The PMPR is comprised of 2 primary components: the MPFL and the MQTFL. Further studies are necessary to determine when these structures should be reconstructed and to what extent concurrent procedures may be required to optimize patient outcomes.

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