Proximal medial patellar restraints and their surgical reconstruction

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Abstract

Reconstruction of the medial patellofemoral ligament (MPFL) has been increasing as a surgical solution for treatment of recurrent lateral patellofemoral dislocation. Recent attention has been given to fibers extending from the femur to the quadriceps tendon, proximal to the MPFL, termed the medial quadriceps tendon-femoral ligament. This article briefly reviews the proximal medial patellar restraints and surgical procedures for their reconstruction.

Keywords: Medial patellar femoral ligament, Proximal medial patellar restraints, Patellar instability

Introduction

Knowledge of patellofemoral (PF) joint pathophysiology and kinematics continues to evolve. Several anatomic structures have been identified as playing a role in the biomechanics and pathophysiology of injury to the medial side of this joint. These structures are typically divided into dynamic and static stabilizers. Historically, the static stabilizers have been labeled the patella retinaculum, and include the medial patellofemoral ligament (MPFL) and patellotibial ligament. More recently, the medial patellotibial ligament (MPTL) and medial patellomeniscal ligament (MPML) have gained recognition in literature [1, 2], as well as the medial quadriceps tendon-femoral ligament (MQTFL) [3, 4].

With the increasing recognition of the medial patellar restraints, one can divide these ligaments into the proximal medial patellar restraints (MQTFL + MPFL) and the distal medial patellar restraints (MPTL + MPML).

Classically, PF joint stabilizing procedures have involved alteration of dynamic stabilizers, in particular the vastus medialis obliquus (VMO) muscle. Literature has shown that static stabilizers, in particular the MPFL, play an important role in patellofemoral biomechanics [5–7], showing correlations with injury when measured using advanced radiographic techniques including magnetic resonance imaging (MRI) [8–10] or stress x-rays [11], and surgically after injury [12–14]. As a result, current procedures involve static stabilizers of the patellofemoral joint, especially the medial patellofemoral ligament (MPFL) and lateral retinacular complex. Reconstruction of the MPFL has become more common as a surgical solution for treatment of recurrent lateral patellofemoral dislocation [15].

This article briefly reviews the proximal medial patellar restraints and surgical procedures for their reconstruction.

Brief literature review

In 1948, Last et al. [16] described the medial anatomy of the knee joint, stating that strong retinacular fibers extend from the medial border of the patella “towards the medial collateral ligament.” The MPFL, though not described by name, inserted distal to, or underneath, the femoral insertion of the medial collateral ligament (MCL).

In 1979, Warren and Marshall [17] published a thorough description of the medial side of the knee that was organized into a three-layer system. The MPFL and medial retinaculum are extracapsular structures described within layer II, the same layer as the superficial MCL. The authors describe a common insertion site of the MCL, MPFL, and the adductor magnus tendon on the medial epicondyle. The medial retinacular ligaments...
were identified as thickening of tissue planes more than independent structures. They further state that, on the medial side of the knee, this three-layer anatomy is often intimately intertwined, with only a few places where three distinct layers could be clearly separated.

Over a decade later, in 1993, Conlan et al. [5] published a paper describing an anatomic and biomechanical study of the medial soft tissue restraints of the patellofemoral joint. In the authors’ in vitro cutting study, the contribution of the MPFL to medial static restraint ranged from 23 to 80%.

A consistent anatomic feature that can be utilized to locate the MPFL is identification of the “triangle” described by Tuxøe et al. [18] and discussed by Feller et al. [19] (Fig. 1). This triangle or bare spot is formed by the adductor magnus tendon medially, VMO fibers superolaterally, and the superior border of the MPFL distally.

Medial patellofemoral ligament anatomy was further defined by Smirk et al. [20], who described equally suitable sites for graft attachment during reconstruction. The femoral attachment site of the MPFL was not uniform, with the most common site being the posterior portion of the medial epicondyle, approximately 1 cm distal to the adductor tubercle (Fig. 2). This insertion site was in isolation 44 % of the time. In another 40 %, the attachment was part of a wider area including the adductor magnus tendon (12 %), the area just posterior to this (20 %), or some combination of the above (4 %).

In 16 %, the MPFL was found attached to the anterior part of the medial epicondyle.

An anatomic review of the medial patellofemoral ligament by Amis et al. [21] noted the lack of consistency in literature regarding the MPFL femoral attachment, and suggested that the convergence of a number of structures and tissue layers towards the medial epicondyle makes it difficult to separate the MPFL. The authors observed that the MPFL fibers decussate as they approach the femoral attachment, and speculated that the MPFL may have two functional bands that run along its proximal and distal fibers.

Nomura et al. [22] dissected 20 knees, and reported an insertion site on the superior–posterior aspect of the medial femoral condyle, just distal to the adductor tubercle (on average 10 mm proximal and 5 mm posterior to the center of the medial epicondyle). On the patella side, VMO fibers cover approximately 35 % of the MPFL as it inserts on the proximal/medial patella. The center point of the MPFL insertion on the patella is at 27 ± 10 % from the upper end of the patella when measured longitudinally on its ventral bony surface.

In 2007, LaPrade et al. [23] reported qualitative and quantitative descriptions of the attachment sites of main medial structures of the knee. For the MPFL, they quantified the midpoint of the MPFL patella attachment as located 41.4 % of the length from the proximal tip of the patella compared with the total patella length. The attachment on the femur was on average 10.6 mm proximal and 8.8 mm posterior to the medial epicondyle, 1.9 mm anterior and 3.8 mm distal to the adductor magnus tendon.
The average length of the MPFL was 65.2 mm [23, 24].

In 2009, Baldwin [25] described the anatomy of the MPFL based on 50 fresh or fresh-frozen anatomic specimens. His eloquent description provided rich anatomic detail of the MPFL femoral insertion. A transverse origin was identified from the bony groove between the medial epicondyle and the adductor tubercle, in addition to a second oblique desiccation originating from the proximal edge of the MCL. Several authors support that the MPFL has multiple fiber extensions to other sites in this region [18, 20, 21, 26, 27] and that it is clearly an extracapsular structure [5, 18, 20, 21, 26].

In the pediatric population, studies consistently cite the MPFL femoral origin distal to the medial distal femoral physis [28, 29].

Recently, attention has returned to the fibers extending from the femur to the quadriceps tendon that have been previously described [20, 21]. These fibers, proximal to the MPFL, have been termed the medial quadriceps tendon-femoral ligament (MQTFL) (Fig. 3) [3, 4]. Despite the presence of proximal fibers, their correlation with injury [10] and the added role of reconstruction of these fibers for patella stabilization is debated.

Near the MQTFL, anatomic descriptions of the MPFL agree on the superior border of the MPFL emanating from the fascial layer on the posterior aspect of the VMO. Therefore, the extent to which the MPFL is “uncovered” in any one specimen depends on the robustness and distal extent of the oblique VMO fibers (Fig. 4). In traumatic patella dislocation, the VMO has been shown to be torn from the adductor tendon, which can result in a more vertical orientation of the VMO fibers. Andrew Amis has commented on the importance of reestablishing the posterior attachments of the VMO to the adductor tendon in order to restore proper VMO fiber orientation (personal communication) (Fig. 5). If one advances the VMO fibers distally without proper posteromedial attachment, one risks a more vertical pull of the VMO, rather than a posteromedial pull intended to help patella tracking (Fig. 6).

MPFL reconstruction

Since its very first description in 1992 by Ellera Gomes et al. [30], MPFL reconstruction has been growing in popularity [31]. Currently, MPFL reconstruction is the cornerstone of surgical treatment of recurrent lateral patellar dislocation [32]. MPFL reconstruction is routinely performed as an isolated or associated procedure that is recognized as safe, reproducible, and effective.

The clinical scenario in which isolated MPFL reconstruction is sufficient to stabilize the patella, without any bony work to compensate or a shallow trochlea, patella alta, or lateralized tibial tubercle, has not yet been categorized with clarity [15]. The original “menu à la carte,” correcting each risk factor when excessive, has been challenged with the current inclusion of MPFL reconstruction in the surgical armamentarium, as reviewed elsewhere [31].

The most widely varied aspects of MPFL reconstruction are:

- **Graft choice**
- **Graft fixation**
- Controlling graft length and its change through the knee arc of motion, which is associated with knee flexion angle at the time of graft fixation and the degree of tautness at the time of graft fixation

Graft choice

Graft choice is an important consideration before MPFL reconstruction. Since the native MPFL has a failure load of approximately 200 N (208 N according to Mountney et al. [33]; 178 N according to LaPrade et al. [34]), the optimal graft should have similar biomechanical properties. The most popular option is autograft, such as gracilis, semitendinosus, quadriceps, quadriceps tendon, and adductor magnus tendons [35–38]. Noyes et al. [39] reported the maximum failure load for the gracilis, semitendinosus, and quadriceps tendon to be 838 N, 1216 N, and 266 N, respectively. All of these options provide higher failure loads than the native MPFL and, therefore, would be appropriate for reconstruction. Depending on availability, allogenic tissue, typically a hamstring graft, can be used. Least common is the use of synthetic grafts [40, 41].

Autografts provide good results and versatility but are affected by donor-site morbidity and graft availability, i.e., previous autograft hamstring anterior cruciate ligament (ACL) reconstruction. Moreover, in very specific conditions such as connective tissue disorders (i.e., Ehlers–Danlos and Marfan syndromes), autografts may not provide sufficient tensile strength for effective reconstruction.

Current literature shows that graft choice does not impact the outcomes of MPFL reconstruction; the choice is made based upon surgeon preference and experience.

Graft fixation

Femoral and patellar fixation during MPFL reconstruction represent another matter of debate, since different methods on both sides have been shown to provide good results.
Patellar fixation

Several types of fixation have been described, including use of anchors [42, 43] or interference screw [44, 45], creation of a two-bone tunnel [35] or a bone bridge [46], and use of a transosseous suture technique [47]. Each technique is characterized by advantages and pitfalls: Although use of bone tunnels provides a stronger fixation force [48, 49], it is also associated with a higher risk of patellar fracture [50, 51]. Patellar fixation with screws or anchors can cause pain and irritation at the insertion site, with one review reporting 1.1 % of patients needing hardware removal [51]. The bone bridge technique showed a maximum load to failure inferior to that of the natural MPFL [52]. Concerning redislocation rate, conflicting results have been published when different techniques were analyzed [51, 53].

Current clinical and biomechanical studies do not identify the best fixation method on the patellar side. For this reason, the patellar fixation method is based on surgeon preference. High-level comparative studies are needed to

Fig. 3  a Cadaveric specimen depicting the undersurface of the medial muscles and soft tissue structures. Outlined is the medial proximal patella femoral complex, which demonstrates fibers originating on the femur and extending to the superior medial patella and quadriceps complex. The superior portion of this complex has been termed the medial quadriceps tendon-femoral ligament (MQTFL). Image courtesy of Miho J. Tanaka MD, Johns Hopkins, Baltimore, MD.  b Cadaveric specimen with the medial muscles translated superiorly. The broad proximal medial patellar restraints are depicted, fanning out from the adductor tubercle to the patella and distal quadriceps complex.
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The MPFL insertion on the patella is broad, described as between 6.1 and 23.1 mm from the superior pole [26]. Radiographically, the patellar insertion is located 7.4 mm anterior to the posterior patellar cortical line and 5.4 mm distal to the perpendicular line intersecting the proximal margin of the patellar articular surface [54]. In literature to date, measurements of the MPFL patellar location have been on the dorsal bony surface. In patellar anatomy with a long distal noncartilaginous portion (the patellar nose), use of the dorsal surface as a measurement guide could lead to poor patellar location, leading to potential pain and/or reduced knee flexion (Fig. 7). Shea et al. investigated the MPFL patellar attachment in pediatric knees and found the attachment to be 4.7 mm superior to the midline of the patella [29]. Although the anatomic location has been well described in literature, its placement appears to be less important than the placement on the femur.

**Femoral fixation**

Femoral fixation methods during MPFL reconstruction can be divided into two basic categories: bone fixation and soft tissue fixation.

Bone tissue fixation still represents the most common technique. Considering this type of fixation, the most frequent method is to create a blind bone tunnel at the femoral anatomical insertion, through which the graft is passed and fixed with an interference screw. Reliable alternatives to this kind of fixation are to secure the graft to the femur by using suspensory loop cortical button [55] or suture anchors [56]. Several studies have reported successful clinical and functional outcomes with the use of femoral tunnel and interference screw [15, 57, 58], with the most widely used technique in published studies being on the femoral side. There are only preliminary published data and descriptions of surgical technique regarding use of cortical button and suture anchors on the femoral side.

Though the first MPFL technique published by Ellera Gomes et al. [30] utilized soft tissue fixation, soft tissue fixation is most used for children and adolescents in order to avoid injury to the open growth plate. Despite its use primarily in children, good results are achieved with soft tissue technique in the adult population. The most common techniques for this kind of femoral fixation include the adductor magnus tenodesis, originally described by Avikainen et al. [59], which uses the adductor sling technique [60], or the medial collateral ligament sling technique [61], the Chassaing technique [62], and the “basket weave” technique as described by Kodkani et al. [63]. Several studies have reported good clinical and functional results using these techniques in the skeletally immature [64–66],

determine which type of fixation provides the best functional results and lowest complication rates for various patient groups, patella size, and bone quality.

However, the location of MPFL graft fixation on the patella is important. Depending on the fixation technique and patella size, inferior graft placement can create increased distal restraint that could be a cause of reduced knee motion and/or pain in deeper knee flexion. For anatomic reconstruction, the center of the graft fixation should be located at the superomedial aspect of the patella, 27% from the superior pole (if the distance between the superior and inferior poles is 100%) [22].
but a higher redislocation rate when soft tissue fixation is compared with bone fixation [64, 66–68]. Soft tissue femoral fixation represents a reliable option in skeletally immature patients.

Regardless of the technique used, the femoral location is critical to surgical success. Improper placement of the femoral tunnel may lead to altered patellofemoral biomechanics and, thus, poorer outcomes. The correct location can be found using radiographic or anatomic landmarks (Fig. 8). Stephen et al. investigated the influence of tunnel placement on patellofemoral contact pressures and biomechanics [69]. Significantly elevated medial contact pressures and medial tilt resulted from too proximal or too distal femoral tunnel positions. These findings have been supported by additional studies showing that proximal tunnel placement overloads the medial patellofemoral compartment, while a tunnel placed too distally would result in a loose, nonfunctional graft [70]. The most popular method of radiographic correlation is using “Schöttle’s point” [71] (Fig. 9), which can be located in the operating room using fluoroscopy and a true lateral radiograph.

Knee flexion angle during fixation
The flexion angle during graft fixation helps determine the “tautness” of the graft with knee motion, and is variable in practice, being highly surgeon dependent. The debate centers on whether one believes in MPFL isometry through knee flexion arc with proper femoral fixation. All are in agreement that we need a fixation location and a ligament “tautness” that does not get tight or stretched in flexion, yet maintains an appropriate lateral restraint in early flexion.

Different studies have reported several knee flexion angles, including 20° [37], 30° [44, 72], 45° [73], 60° [46, 74], and 70° [75]. Based on a previous biomechanical study, Schöttle et al. [71] suggested in 2007 repairing the graft with the knee at 30° of flexion, since in this position the natural MPFL has its maximal restraint against patellar lateralization [21]. However, Stephen et al. [76] could not identify significant differences in patellofemoral contact when changing the knee flexion angle between 0° and 60° during graft fixation. In a recent cadaveric study, Lorbach et al. [77] concluded that fixation at 60° of knee flexion represents the position that most closely restores natural patellofemoral contact pressure, even though flexion angle did not have a significant impact on overall patellofemoral contact pressure.
Graft tension during fixation

Tension means the state of being stretched (noun) or applying a force to something that tends to stretch it (verb). Graft tensioning is of paramount importance during graft fixation, and excessive tension should be avoided since it could be associated with stiffness, overcorrection of the patellar tilt, and early progressive degeneration of the medial patellofemoral joint. Though graft tension and the knee flexion angle at time of fixation are related, they are not synonymous. Proper graft tension, and how to achieve this during fixation, remains debatable.

In a cadaveric study, Philippot et al. [78] stated that the ideal graft tension was 10 N, and the results of this study were implemented in a clinical trial conducted by
Carnesecchi et al. [79], who demonstrated excellent clinical results in 50 patients whose MPFL graft was fixed with tension of 10 N. However, a more recent biomechanical study by Stephen et al. [69] confirming the results previously obtained by Beck et al. [80] stated that a tension of 2 N in an anatomically positioned MPFL graft is sufficient to restore patellar tracking and patellofemoral joint contact pressures to the intact state, whereas tension of 10 N or greater increases medial contact pressure along with medial tilt and translation, particularly when fixation is performed in full extension.

**Postoperative protocol**

The immediate postoperative goal after MPFL reconstruction is to reduce swelling and pain. The goals in the rehabilitative phase are to eliminate pain, regain range of knee motion, and restore quadiceps strength. Postoperative protection of the knee is somewhat dependent on the strength of the graft fixation, but for most current surgical methods, progression is based on functional goals and not time.

The training phase involves regaining strength and normal functional gait pattern. For MPFL reconstruction, this is variable but typically completed by 4–6 weeks. The advanced training phase involves examination of complex body movement patterns, primarily to reduce the risk of reinjury and maximize surgical success. This phase is typically 6–12 weeks postoperatively.

Regarding return to sport, the injured patient is often eager for an expected timeline for return to full function. Estimates can be given, but the athlete and physician must be aware that the ultimate return to activities, be they daily activities or higher-level competition, depends on recovery of strength, flexibility, and appropriate body movement patterns.

Various functional tests, more commonly used in knee ligament surgery, can be employed to aid estimation of patient readiness to return to activities. The average return to sport, depending on patient- and sport-specific factors, is 4–6 months.

**Conclusions**

An explosion of knowledge based on PF anatomy and biomechanics principles has positively influenced treatment of PF injuries, in particular lateral patellar dislocation. Patella stabilization surgery demands broad knowledge of anatomic and biomechanical principles as reviewed herein.

**Abbreviations**

MCL: medial collateral ligament; MPFL: medial patellofemoral ligament; MPML: medial patellomeniscal ligament; MPFL: medial patellofemoral ligament; MQTFL: medial quadriceps tendon-femoral ligament; PF: patellofemoral; VMO: vastus medialis obliquus muscle.

**Authors’ contributions**

All authors contributed substantially in writing, reviewing, and editing the manuscript; additionally, all authors have read and approved the final manuscript. Individual contributions are as follows: PF—literature review, data acquisition, data analysis, data interpretation, supervision, BK—literature review, data acquisition, data analysis, data interpretation, SP—literature review, data acquisition, data analysis, data interpretation, conceptualization, data curation, supervision, validation. All authors read and approved the final manuscript.

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**References**

1. Hinckel B, Gobbi RG, Kaleka CC, Camanho GL, Arendt EA (2018) Medial patellotibial ligament and medial patellomeniscal ligament: anatomy, imaging, biomechanics, and clinical review. Knee Surg Sports Traumatol Arthrosc 26(3):895–896
2. Kruckenberg BM, Chahla J, Moatshe G, Cinque ME, Muckenhirn KJ, Godin JA, Ridley TJ, Brady AW, Arendt EA, LaPrade RF (2018) Quantitative and qualitative analysis of the medial patellar ligaments: an anatomic and radiographic study. Am J Sports Med 46(1):153–162
3. Fulkerson JP, Edgar C (2013) Medial quadriceps tendon-femoral ligament: surgical anatomy and reconstruction technique to prevent patella instability. Arthrosc Tech 2(2):e125–e128
4. Tanaka MJ (2016) Variability in the patellar attachment of the medial patellofemoral ligament. Arthroscopy 32(8):1667–1670
5. Conlan T, Garth WP Jr, Lemons JE (1993) Evaluation of the medial soft-tissue restraints of the extensor mechanism of the knee. J Bone Joint Surg Am 75(5):682–693
6. Hautamaa PV, Fithian DC, Kaufman KR, Daniel DM, Pohlmeyer AM (1998) Medial soft tissue restraints in lateral patellar instability and repair. Clin Orthop Relat Res 349:174–182
7. Burks RT, Desio SM, Bachus KN, Tyson L, Springer K (1998) Biomechanical evaluation of lateral patellar dislocations. Am J Knee Surg 11(1):24–31
8. Askenberger M, Janav P-M, Finnbogason T, Arendt EA (2017) Morphology and anatomic patellar instability risk factors in first-time traumatic lateral patellar dislocations: a prospective magnetic resonance imaging study in skeletally immature children. Am J Sports Med 45(1):50–58
9. Arendt EA, England K, Agel J, Tompkins MA (2017) An analysis of knee anatomic imaging factors associated with primary lateral patellar dislocations. Knee Surg Sports Traumatol Arthrosc 25(10):3099–3107
10. Tompkins MA, Rohr SR, Agel J, Arendt EA (2018) Anatomic patellar instability risk factors in primary lateral patellar dislocations do not predict injury patterns: an MRI-based study. Knee Surg Sports Traumatol Arthrosc 26(3):677–684
11. Teige RA, Faebler W, Des Madryl P, Matelic TM (1996) Stress radiographs of the patellofemoral joint. J Bone Joint Surg Am 78(2):193–203
12. Sallay PJ, Poggi J, Speer KP, Garrett WE (1996) Acute dislocation of the patella. A correlative pathoanatomic study. Am J Sports Med 24(1):52–60
13. Nomura E (1999) Classification of lesions of the medial patello-femoral ligament in patellar dislocation. Int Orthop 23(5):260–263
14. Nomura E, Horiuchi Y, Inoue M (2002) Correlation of MR imaging findings and open exploration of medial patellofemoral ligament injuries in acute patellar dislocations. Knee 9(2):139–143
15. Tompkins MA, Arendt EA (2015) Patellar instability factors in isolated medial patellofemoral ligament reconstructions—what does the literature tell us? A systematic review. Am J Sports Med 43(9):2318–2327
16. Last RJ (1948) Some anatomical details of the knee joint. J Bone Joint Surg Br 30(4):683–688
17. Warren LF, Marshall JL (1979) The supporting structures and layers on the medial side of the knee: an anatomical analysis. J Bone Joint Surg Am 61(1):56–62
18. Tuxoe JL, Teir M, Winge S, Nielsen PL (2002) The medial patellofemoral ligament: a dissection study. Knee Surg Sports Traumatol Arthrosc 10(3):138–140
19. Feller JA, Feagin JA Jr, Garrett WE Jr (1993) The medial patellofemoral ligament revisited: an anatomical study. Knee Surg Sports Traumatol Arthrosc 1(3–4):184–186
20. Simic M, Morris H (2003) The anatomy and reconstruction of the medial patellofemoral ligament. Knee 10(3):221–227
21. Amin AA, Firer P, Mountney J, Senavongse W, Thomas NP (2003) Anatomy and biomechanics of the patellofemoral ligament. Knee 10(3):215–220
22. Nomura E, Inoue M, Osada N (2005) Anatomical analysis of the medial patellofemoral ligament of the knee, especially the femoral attachment. Knee Surg Sports Traumatol Arthrosc 13(7):510–515
23. LaPrade RF, Engebretsen AL, Ly TV, Johansen S, Wentorf FA, Engebretsen L (2007) The anatomy of the medial part of the knee. J Bone Joint Surg Am 89(9):2000–2010
24. Wijdicks CA, Griffith CJ, LaPrade RF, Johansen S, Sunderland A, Arendt EA, Engebretsen L (2009) Radiographic identification of the primary medial knee structures. J Bone Joint Surg Am 91(3):521–529
25. Baldwin JI (2009) The anatomy of the medial patellofemoral ligament. Am J Sports Med 37(12):2355–2362
26. Steenssen RN, Dopiak RM, McDonald WG 3rd (2004) The anatomy and isometry of the medial patellofemoral ligament: implications for reconstruction. Am J Sports Med 32(6):1509–1513
27. Nomura E, Horiuchi Y, Khara M (2000) Medial patellofemoral ligament restraint in lateral patellar translation and reconstruction. Knee 7(2):121–127
28. Neltz M, Dornacher D, Dreyhaupj, Reichel H, Lippacher S (2011) The relation of the distal femoral physeal and the medial patellofemoral ligament. Knee Surg Sports Traumatol Arthrosc 19(12):2067–2071
29. Shea KG, Polousky JD, Jacobs JCL, Ganley TJ, Aoki SK, Grimm NL, Parikh SN (2015) The patellar insertion of the medial patellofemoral ligament in children: a cadaveric study. J Pediatr Orthop 35(4):e31–e35
30. Ellera Gomes JL (1992) Medial patellofemoral ligament reconstruction for recurrent dislocation of the patella: a preliminary report. Arthroscopy 8(3):335–340
31. Arendt EA, Donnell ST, Sillampää PI, Feller JA (2017) The management of lateral patellar dislocation: state of the art. JISAKOS 2(4):205–212
32. Burrus MT, Tompkins MA, Hinckel BB, Diduch DR, Arendt EA (2017) Repair and reconstruction of the patellofemoral ligament for treatment of lateral patellar dislocations. Surgical techniques and clinical results. In: Scott WN (ed) Insall & Scott Surgery of the Knee, 6th edn. Elsevier, Philadelphia, pp 939–953
33. Mountney J, Senavongse W, Amis AA, Thomas NP (2005) Tensile strength of the medial patellofemoral ligament before and after repair or reconstruction. J Bone Joint Surg Br 87(1):36–40
34. LaPrade MD, Kallenbach SL, Aman Z, Storaci HW, Turnbull TL, Arendt EA, Chahla J, LaPrade RF (2018) Biomechanical evaluation of the medial stabilizers of the patella. Am J Sports Med 46(7):1575–1582
35. Christiansen S, Jacobsen BW, Lund B, Lind M (2008) Reconstruction of the medial patellofemoral ligament with gracilis tendon autograft in transverse patellar drill holes. Arthroscopy 24(1):82–87
36. Schottle PB, Romero J, Schmeling A, Weiler A (2008) Technical note: anatomical reconstruction of the medial patellofemoral ligament using a free gracilis autograft. Arch Orthop Trauma Surg 128(5):479–484
37. Fink C, Veselko M, Herbst M, Hoser C (2014) MPFL reconstruction using a quadriceps tendon graft: Part 2. Operative technique and short term clinical results. Knee 21(6):1175–1179
38. Singhal R, Rogers S, Charalambous CP (2013) Double-bundle medial patellofemoral ligament reconstruction with hamstring tendon autograft and mediolateral patellar tunnel fixation: a meta-analysis of outcomes and complications. Bone Joint J 95(8):900–905
39. Noyes FR, Butler DL, Good ES, Zernicke RF, Helzy MS (1984) Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. J Bone Joint Surg Am 66(3):344–352
40. Berruto M, Ferrua P, Ulbofidi F, Usellini E, Gala L, Tassi A, Marelli B (2014) Medial patellofemoral ligament reconstruction with bioactive synthetic ligament is an option. A 3-year follow-up study. Knee Surg Sports Traumatol Arthrosc 22(10):2419–2425
41. Lee PFF, Golding D, Rozwieszci, Chandratya A (2018) Modern synthetic material is a safe and effective alternative for medial patellofemoral ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 26(9):2716–2721
42. Schottke PB, Fucentese SF, Romero J (2005) Clinical and radiological outcome of medial patellofemoral ligament reconstruction with a semitendinosus autograft for patella instability. Knee Surg Sports Traumatol Arthrosc 13(7):516–521
43. Song SY, Kim IS, Chang HG, Shin J-H, Kim HI, Seo Y-J (2014) Anatomic medial patellofemoral ligament reconstruction using patellar suture anchor fixation for recurrent patellar instability. Knee Surg Sports Traumatol Arthrosc 22(10):2431–2437
44. Schottke PB, Hensler D, Inhoff AB (2010) Anatomical double-bundle MPFL reconstruction with an aperture fixation. Knee Surg Sports Traumatol Arthrosc 18(2):147–151
45. Hapa O, Aksahin E, Ozden R, Pepe M, Yanat AN, Dogramaci Y, Bozdag E, Sunbuloglu E (2012) Aperture fixation instead of transverse tunnels at the patella for medial patellofemoral ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 20(2):322–326
46. Hermad CS, Brown GD, Stein BS (2009) The docking technique for medial patellofemoral ligament reconstruction: surgical technique and clinical outcome. Am J Sports Med 37(10):2021–2027
47. Petersen W, Zantop T (2009) Eine neue methode zur patellaren fixation von MPFL-transplantaten [A new method for the patellar fixation of MPFL grafts]. Arthroskopie 22(3):237–240
48. Russ SD, Tompkins M, Nuckley D, Macalena J (2015) Biomechanical comparison of patellar fixation techniques in medial patellofemoral ligament reconstruction. Am J Sports Med 43(1):195–199
49. Russ F, Doan J, Chase DC, Farinsworth CL, Penkock AT (2016) Medial patellofemoral ligament reconstruction: fixation technique biomechanics. J Knee Surg 29(4):303–309
50. Parikh SN, Wall EJ (2011) Patellar fracture after medial patellofemoral ligament surgery: a report of five cases. J Bone Joint Surg Am 93(17):e971–988
51. Shah JN, Howard JS, Flanigan DC, Brophy RH, Carey JL, Lattermann C (2012) A systematic review of complications and failures associated with medial patellofemoral ligament reconstruction for recurrent patellar dislocation. Am J Sports Med 40(8):1916–1927
53. Heo J-W, Ro K-H, Lee D-H (2018) Patellar redislocation rates and clinical outcomes after medial patellofemoral ligament reconstruction: suture anchor versus double transpatellar tunnel fixation. Am J Sports Med. https://doi.org/10.1177/0363546518764548

54. Barnett AJ, Howells NR, Burston BJ, Ansari A, Clark D, Eldridge JD (2012) Radiographic landmarks for tunnel placement in reconstruction of the medial patellofemoral ligament. Knee Surg Sports Traumatol Arthrosc 20(12):2380–2384

55. Godin JA, Karas V, Visgauss JD, Garrett WE (2015) Medial patellofemoral ligament reconstruction using a femoral loop button fixation technique. Arthrosc Tech 4(5):e601–e607

56. Calanna F, Pulici L, Carimati G, Quaglia A, Volpi P (2016) Medial patello-femoral ligament (MPFL) reconstruction using suture anchors fixation: preliminary results. Muscles Ligaments Tendons J 6(1):64–70

57. Schneider DK, Grawe B, Magnussen RA, Ceasar A, Parikh SN, Wall EJ, Casolo AJ, Kaeding CC, Myer GD (2016) Outcomes after isolated medial patellofemoral ligament reconstruction for the treatment of recurrent lateral patellar dislocations: a systematic review and meta-analysis. Am J Sports Med 44(11):2993–3005

58. Stupay KL, Swart E, Shubin Stein BE (2015) Widespread implementation of medial patellofemoral ligament reconstruction for recurrent patellar instability maintains functional outcomes at midterm to long-term follow-up while decreasing complication rates: a systematic review. Arthroscopy 31(7):1372–1380

59. Avikainen VJ, Nikku RK, Seppanen-Lehmonen TK (1993) Adductor magnus tenodesis for patellar dislocation. Technique and preliminary results. Clin Orthop Relat Res 297(297):12–16

60. Sillanpää PI, Mäenpää MH, Arendt EA (2010) Treatment of lateral patella dislocation in the skeletally immature athlete. Oper Tech Sports Med 18(2):83–92

61. Deie M, Ochi M, Sumen Y, Adachi N, Kobayashi K, Yasumoto M (2005) A long-term follow-up study after medial patellofemoral ligament reconstruction using the transferred semitendinosus tendon for patellar dislocation. Knee Surg Sports Traumatol Arthrosc 13(7):522–528

62. Chassaing V, Trémoulet J (2005) Plastie du ligament fémoro-patellaire médial avec le tendon du gracile pour stabilisation de la patella [Medial patellar dislocation. Knee Surg Sports Traumatol Arthrosc 13(7):522–528]. Rev Chir Orthop Reparatrice Appar Mot 91(4):335–340

63. Kodkani PS (2015) Basket-weave technique for medial patellofemoral ligament reconstruction. Arthrosc Tech 4(3):e279–e286

64. Alm L, Krause M, Mull C, Frosh K-H, Akoto R (2017) Modified adductor sling technique: a surgical therapy for patellar instability in skeletally immature patients. Knee 24(6):1282–1288

65. Vavken P, Wimmer MD, Camathias C, Quidde J, Valderrabano V, Pagnersteg G (2013) Treating patella instability in skeletally immature patients with the transferred semitendinosus tendon for patellar dislocation. Technique and preliminary results. Knee Surg Sports Traumatol Arthrosc 21(8):2251–2256

66. Lind M, Enderlein D, Nielsen T, Christiansen SE, Fauno P (2016) Clinical outcome after reconstruction of the medial patellofemoral ligament in paediatric patients with recurrent patella instability. Knee Surg Sports Traumatol Arthrosc 24(5):666–671

67. Nellitz M, Dreyhaupt J, Reichel H, Woeffle J, Lippacher S (2013) Anatomic reconstruction of the medial patellofemoral ligament in children and adolescents with open growth plates: surgical technique and clinical outcome. Am J Sports Med 41(1):58–63

68. Nellitz M, Dreyhaupt J, Williams SRM. (2018) Anatomic reconstruction of the medial patellofemoral ligament in children and adolescents using a pedicled quadriceps tendon graft shows favourable results at a minimum of 2-year follow-up. Knee Surg Sports Traumatol Arthrosc 26(6):1210–1215

69. Stephen JM, Kader D, Lumpaopong P, Deehan DJ, Amis AA (2014) The effect of femoral tunnel position and graft tension on patellar contact mechanics and kinematics after medial patellofemoral ligament reconstruction. Am J Sports Med 42(2):364–372

70. Elias JJ, Cosgarea AJ (2006) Technical errors during medial patellofemoral ligament reconstruction could overload the medial patellofemoral cartilage. A computational analysis. Am J Sports Med 34(9):1478–1485

71. Schöttle PB, Schmelning A, Rosenstiel N, Weiler A (2007) Radiographic landmarks for femoral tunnel placement in medial patellofemoral ligament reconstruction. Am J Sports Med 35(5):801–804

72. Enderlein D, Nielsen T, Christiansen SE, Fauno P, Lind M (2014) Clinical outcome after reconstruction of the medial patellofemoral ligament in patients with recurrent patella instability. Knee Surg Sports Traumatol Arthrosc 22(10):2458–2464

73. Kim T-S, Kim H-J, Ra H-H, Kyung H-S (2015) Medial patellofemoral ligament reconstruction for recurrent patellar instability using a gracilis autograft without bone tunnel. Clin Orthop Surg 7(4):457–464

74. Berruto M, Ferrua P, Tradati D, Uboldi F, Usellini E, Marelli BM (2017) Suture anchors fixation in MPFL reconstruction using a bioactive synthetic ligament. Joints 5(3):188–196

75. Ntagiopoulos PG, Sharma B, Bigiuzzo S, Lopomo N, Colle F, Zaffagnini S, Dejpur D. (2013) Are the tubular grafts in the femoral tunnel in an anatomical or isometric position in the reconstruction of medial patellofemoral ligament? Int Orthop 37(10):1933–1941

76. Stephen JM, Lumpaopong P, Deehan DJ, Kader D, Amis AA (2012) The medial patellofemoral ligament: location of femoral attachment and length change patterns resulting from anatomic and nonanatomic attachments. Am J Sports Med 40(8):1278–1283

77. Berruto M, Ferrua P, Tradati D, Uboldi F, Usellini E, Marelli BM (2017) Suture anchors fixation in MPFL reconstruction using a bioactive synthetic ligament. Joints 5(3):188–196

78. Ntagiopoulos PG, Sharma B, Bigiuzzo S, Lopomo N, Colle F, Zaffagnini S, Dejpur D (2013) Are the tubular grafts in the femoral tunnel in an anatomical or isometric position in the reconstruction of medial patellofemoral ligament? Int Orthop 37(10):1933–1941

79. Stephen JM, Lumpaopong P, Deehan DJ, Kader D, Amis AA (2012) The medial patellofemoral ligament: location of femoral attachment and length change patterns resulting from anatomic and nonanatomic attachments. Am J Sports Med 40(8):1278–1283

80. Beck P, Brown NAT, Greis PE, Burks RT (2007) Patellofemoral contact pressure—a biomechanical study. Arthroscopy 34(4):1072–1082

81. Philippot R, Boyer B, Testa R, Farizon F, Moyen B (2012) The role of the medial ligamentous structures on patellar tracking during knee flexion. Knee Surg Sports Traumatol Arthrosc 20(2):331–336

82. Carnesecchi O, Neri T, Falvi G, Zaffagnini S, Dejpur D (2013) Are the tubular grafts in the femoral tunnel in an anatomical or isometric position in the reconstruction of medial patellofemoral ligament? Int Orthop 37(10):1933–1941

83. Philippot R, Boyer B, Testa R, Farizon F, Moyen B (2012) The role of the medial ligamentous structures on patellar tracking during knee flexion. Knee Surg Sports Traumatol Arthrosc 20(2):331–336

84. Beck P, Brown NAT, Greis PE, Burks RT (2007) Patellofemoral contact pressure—a biomechanical study. Arthroscopy 34(4):1072–1082

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