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Isometric behavior of the reconstructed medial patellofemoral ligament using two different femoral pulleys: A cadaveric study

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A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
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Summary

Background: Several techniques have been described for reconstructing the medial patellofemoral ligament (MPFL). However, the anatomy of the medial patellar retinaculum and the isometry of both intact and reconstructed MPFL remain controversial. The purpose of this study was to investigate the isometric behavior of the reconstructed MPFL when two different pulleys are used for the reconstruction.

Material/Methods: Eight anatomical knees were dissected and the medial patellar retinaculum and MPFL were studied. A pilot technique for the reconstruction of the MPFL using a semitendinosus autograft was developed. A "dynamic" femoral fixation was chosen which utilized two different pulleys: the medial intermuscular septum (MIS) at the adductor's tendon insertion and the posterior third of the medial collateral ligament (MCL). The isometric behavior of the reconstructed MPFL and the stability of both pulleys were investigated.

Results: The MPFL was a thickened, band-like condensation of the superficial MPR layer extending from the MFE to the medial border of the patella. The reconstructed MPFL demonstrated the most isometric behavior when the MCL was used as a pulley. The average difference in graft length during knee flexion from 0° to 90° when the MCL or MIS were used as a pulley was 1 mm and 4 mm, respectively. The MIS pulley was more stable but less isometric than the MCL pulley.

Conclusions: "Dynamic" MPFL reconstruction with a semitendinosus tendon autograft can restore patellofemoral stability without excessive soft-tissue dissection or implantation of hardware at the medial epicondyle, which can lead to symptoms of its own.

key words: **medial patellar retinaculum • medial patellofemoral ligament • patella • anatomy • isometry**

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Background

Recurrent dislocation, subluxation, and functional instability due to patellofemoral pain can affect up to one half of patients who present with a first-time dislocation and no prior history of patellofemoral complaints [1,2]. Maenpaa and Lehto [3] reported the clinical results of 100 patients with primary acute patella dislocations treated with various non-operative techniques. At an average 13-year follow-up, 44% re-dislocated and a further 19% had ongoing patellofemoral pain and subluxation, leading to an overall 63% of patients reporting unsatisfactory results over a substantial follow-up period. Surgical management of traumatic patella dislocation may have gained wider acceptance had it not been for our poor understanding of the pathoanatomy of the injury as compared with, say, ACL rupture. A plethora of various surgical techniques in small numbers of patients with mixed results has been reported. Some of these procedures carry a significant morbidity of their own, thereby dissuading most orthopedic surgeons from their routine use in this very common knee injury.

It is the authors' opinion that the prerequisites of successful surgical management of traumatic patella instability are: a) evolving knowledge of the anatomy of static and dynamic patella stabilizers, b) the isometricity of the dynamic stabilizers, and c) a surgical technique that does not significantly alter the patient's pre-morbid anatomy potentially leading to complications related to over-constraint and reverse (medial) instability. Disruption of the capsule, medial patellar retinaculum, and/or vastus medialis obliquus [4,5] have been associated with recurrent patella instability, but recently the medial patellofemoral ligament (MPFL) has been recognized as the most important ligamentous stabilizer preventing lateral dislocation of the patella [6,7]. Nomura [8] reported a high incidence of MPFL rupture or insufficiency in both acute (18/19 knees) and chronic (49/49) cases with patella dislocation.

As the role of the MPFL in lateral translation of the patella has been established over the last decade [9,10], numerous anatomic [4,11–22] and/or clinical [23–35] studies have advocated either direct repair or reconstruction of the ligament. There is still disagreement regarding the origin and especially the femoral attachment of the ligament [15,20], and therefore disagreement on the isometric position in the intact MPFL. The present cadaveric study was indented to a) clarify the anatomic peculiarities of the medial patellar retinaculum (MPR) and especially its main constituent part, the MPFL, b) develop a technique of MPFL reconstruction using a semitendinosus tendon autograft, and c) study the isometry of the reconstructed MPFL using either the medial intermuscular septum (MIS) insertion into the adductor's tubercle (AT) or the medial collateral ligament (MCL) insertion into the medial femoral epicondyle (MFE) as condign pulleys. Our main hypothesis was that the MIS can be used as an alternative pulley for the reconstruction of the MPFL.

Material and Methods

Eight anatomical knees (four cadavers) were provided by the Human Anatomy Laboratory, Robert Jones & Agnes Hunt Orthopaedic Hospital, Oswestry, for the study. The agreement with the Laboratory was to avoid dismembering the cadavers to allow for further anatomy teaching purposes. Two cadavers were male and two female, with an average age of 76.5 years. No antemortem history was available, but none of the specimens had evidence of any significant injury or previous surgery.

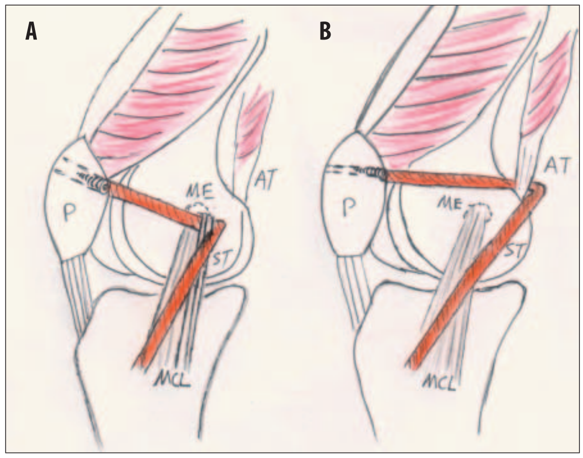


Figure 1. Schematic representation of the two different techniques of MPFL reconstruction. (**A**) passage of the semitendinosus tendon (ST) through the posterior 1/3 of the medial collateral ligament (MCL), (**B**) the ST is passed through the adductor's tendon at the adductor's tubercle (AT). In both techniques the ST is fixed to the superomedial border of the patella (P).

The study consisted of three parts: 1) the first was to define the anatomy of the MPR and the anatomic relationship of the MPFL with the neighboring bony and soft-tissue structures, 2) the second consisted of sectioning and temporary reconstruction of the MPFL with the ipsilateral semitendinosus tendon (ST) using two different techniques. Maintaining the tibial attachment, the proximal part of the tendon was passed retrograde to the superomedial border of the patella using either the attachment of the medial intermuscular septum (MIS) to the adductor's tubercle (AT) or the proximal attachment of the medial collateral ligament (MCL) to the medial femoral epicondyle (MFE) as pulleys to procure the desired vector of medial force (Figure 1). 3) The third part was to define the isometric behavior of the two different reconstructions and the potential advantages and pitfalls using either the MCL or MIS as pulleys.

Anatomy of the medial patellar retinaculum

Skin and subcutaneous tissue was removed from the entire lower limb in all specimens. The medial retinaculum was dissected to allow identification of the respective layers. The MPFL was recognized as a thickened, band-like condensation of tissue extending from the tissue between the MFE inferiorly and the AT superiorly to the superomedial border of the patella. The origins, insertion size, fiber orientation, and anatomic relations of the MPFL to the patella, AT, MFE, vastus medialis obliquus (VMO), and MCL were recorded.

Reconstruction of the MPFL

The semitendinosus tendon (ST) was divided at its musculotendinus junction using an open tendon stripper, leaving

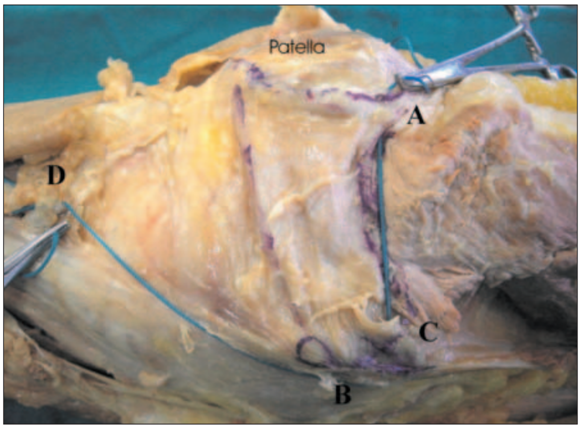
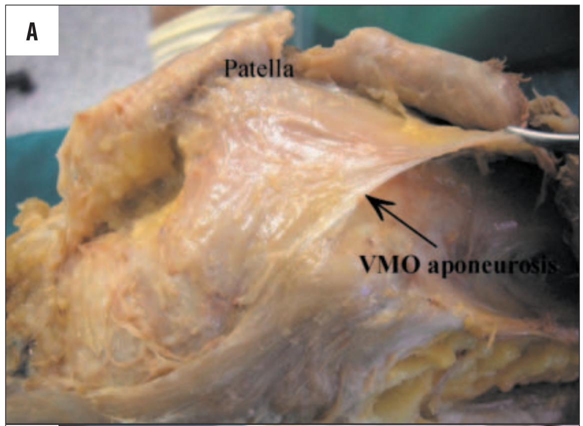


Figure 2. Evaluation of graft isometry by marking four points: (**A**) the insertion of ST to the patella, (**B**) the MCL pulley, (**C**) the MIS pulley, and (**D**) the tibial insertion of the ST. (The suture indicates the route of the reconstructed MPFL when the MIS is used as the pulley.) [X – adductor's tubercle, 0 – medial femoral epicondyle].



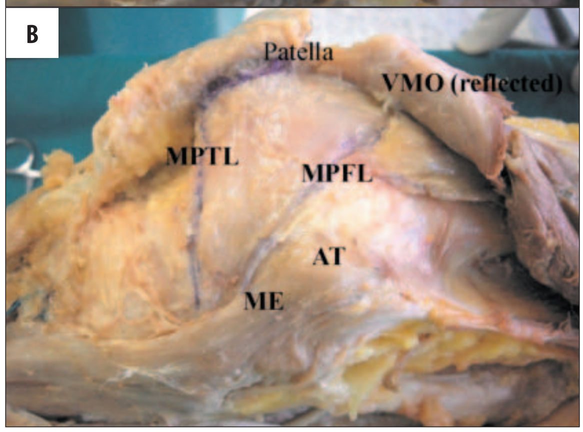


Figure 3. (**A**) The superficial layer of the medial patellar retinaculum is formed by the aponeurosis of the vastus medialis obliquus (VMO) and the superficial fibers of the MPFL. (**B**) The deep layer is a transversely orientated Y-shaped structure. The combined limb attaches to the medial border of the patella and superior third of the medial border of the patella tendon. The inferior limb attaches to the middle third of the medial collateral ligament and medial meniscus. This is called the medial patellotibial ligament (MPTL). The superior limb (deep fibers of MPFL) is anchored to the bone just distal to the adductor tubercle (AT) or superoposterior to the medial femoral epicondyle (ME).

the tibial attachment intact. The tendon was whip-stitched to a length of 4–5 cm with Ethibond No. 2 sutures (Ethicon, Edinburgh, UK). A 1-cm split was made in the posterior one-third of the femoral attachment of MCL and the harvested tendon was passed through the pulley, as has been described by Deie et al. [14,15], and transferred to the patella. The tendon was passed through a 5.5-mm tunnel from the superomedial to the inferolateral border of the patella and under a moderate medial force and the knee, flexed at 50–60°, was thereafter fixed to the superomedial border using a Biotenodesis screw (Arthrex Ltd., Sheffield, UK). The superomedial edge of the patella was used for the ST fixation as it is considered the more isometric point of the MPFL insertion to the patella [44]. After the isometry measurements, the ST was re-routed through the distal part of the medial intermuscular septum (MIS) just above the adductor's tubercle (AT) and was fixed again to the superomedial border of the patella. Isometry measurements were again carried out.

Isometry of the reconstructed MPFL

The isometry of the reconstruction was measured by four points: on (A) the insertion of the ST to the patella, (B) the MCL pulley, (C) the MIS pulley, and (D) the tibial insertion of the ST (Figure 2). The distanced between the points at various fixed angles of knee flexion (0°, 30°, 60°, and 90°) were measured using a standard goniometer. We deemed that measurements above 90° of knee flexion would not contribute substantially to our study as it is well known that patellofemoral instability is reflected typically during early flexion of the knee joint. All measurements were obtained by the same researcher (I.T.) to avoid inter-observer error. Intra-observer error was also minimized by double-measuring the fixed angles and the distances between all the aforementioned points.

At a range of flexion between 0° and 30°, manual tension was applied in line with the quadriceps tendon to stretch the extensor mechanism. Heavy sutures were passed through the patellar tendon and gentle tension was applied manually in line with the tendon until the extensor mechanism was visually and palpably taut. The tautening was performed by the same researcher (A.P.) in all specimens in order to keep the degree of tensioning relatively consistent. At higher flexion angles, the natural tension of the extensor mechanism was used.

Stability of the MIS and MCL pulleys

Before and after 100 repeated passive knee circles (0–120°), the D-B and D-C distances (tibial attachment of ST to each pulley) were measured. The measurements were taken with the knee at 90°, and similar index values after repeated measurements were indicative of a fixed pulley, whereas different values defined a loose pulley.

Data collection and analysis

After data collection was completed, the data were analyzed to determine which route of the ST graft was more isometric

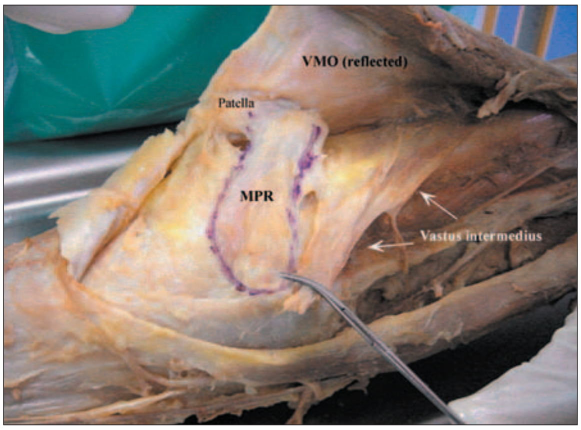


Figure 4. The contribution of the vastus intermedius (pulled by the clip) to the deep layer of the medial patellar retinaculum.

and which pulley was more stable. The three-way ANOVA test was used as the primary statistical test.

Results

Anatomy of the medial patellar retinaculum

The bony attachments of the medial retinaculum were confirmed to be the medial femoral epicondyle (MFE), the adductor's tubercle (AT), and the medial border of the patella. The medial patellar retinaculum had a distinctive superficial and deep layer (Figure 3).

Superficial layer

- Formed by the aponeurosis of the VMO (muscular/dynamic part).
- The superficial MPFL fibers pass from the MFE, adductor tubercle, and medial intermuscular septum to the medial border of the patella.

Deep layer

- Transversely orientated Y-shaped structure. The combined limb attaches to the medial border of the patella and the superior third of the medial border of the patellar tendon.
- The superior limb (deep fibers of the MPFL) is anchored to the bone just distal to the adductor tubercle or superoposterior to the medial femoral epicondyle and consistently receives a contribution from the vastus intermedius muscle (Figure 4).
- The inferior limb attaches to the middle third of the MCL and medial meniscus. This is called the medial patellotibial ligament (MPTL).

The MPFL therefore represents a section of the superficial part of the MPR and was easily exposed when the posterior fibers of the VMO were reflected anteriorly. The femoral origin of the ligament was located between the MFE, AT, and the intervening tissue as well as the MIS. The mean length of the MPFL was 55.4 mm (range: 48–61 mm). The average width of the femoral origin of MPFL was 15.5 mm (12–19 mm) and of the patellar insertion 17.5 mm (14–21 mm). The vertical distance from the superior pole of the patella to the superior edge of the MPFL patellar insertion was 7.5 mm (1–16 mm) and to the inferior edge of the MPFL patellar insertion 20 mm (15–28 mm).

Table 1. Average length (mm) of semitendinosus tendon graft for the reconstruction of medial patellofemoral ligament when medial collateral ligament (MCL) and medial intermuscular septum (MIS) are used as pulleys.

Knee flexion	0°	30°	60°	90°
D-B	70	72	72	72
A-B	57	56	56	56
Total length through MCL	127	128	128	128
D-C	84	85	85	85
A-C	57	60	60	60
Total length through MIS	141	145	145	145

Table 2. Graft length (mm) from its tibial insertion (D) to the MIS pulley (C) or the MCL pulley (B) before and after flexion-extension cycling of the knee (100 cycles from 0° to 120°).

At 90° of knee flexion	Before cycling	After cycling
D-C	85	85
D-B	72	70

Isometry of the graft

The reconstructed MPFL demonstrated the most isometric behavior when the MCL was used as a pulley (Table 1). The average differences in graft length during knee flexion from 0° to 90° when the MCL or MIS were used as a pulley were 1 mm and 4 mm, respectively. The distance A-B (MCL pulley) was more isometric than the distance A-C (MIS pulley). However, no differences were found in both groups at 30°, 60°, and 90° when the total length of the graft (from ST tibial insertion to its patellar insertion) was measured.

After 100 repetitive cycles of the knee through a 0° to 120° range of motion, the graft length from its tibia insertion to the MCL pulley (D-B) was reduced by 2 mm on average at 90° of flexion. In contrast, the graft length from its tibia insertion to the MIS pulley (D-C) remained unchanged when measured at 90° of flexion. (Table 2).

Discussion

Many non-anatomical surgical techniques for the treatment of recurrent patellar dislocation have been described in the literature [9,36–43]. These procedures alter the premorbid patella mechanics by several principles, including the release of tight lateral ligaments, tensioning of loose medial structures, and distal realignment of the extensor mechanism or a combination of these. The outcomes are inconsistent and many studies have reported recurrent dislocations and patellofemoral pain and arthritis in up to 40% [39–41]. Isolated lateral retinacular release with or without division of the vastus lateralis tendon relies on the uncontrolled lengthening of uninjured tissue on the lateral side of the patella to counteract the effects of a damaged medial patellar retinaculum and can lead to re-dislocation rates of up to 40% [37]. The potential for creating a multidirectional instability of the patella is significant [44–46], even though this complication was not reported in the 20 subjects of Woods et al. [47].

Medial reefing advances the VMO aponeurosis, but fails to address injuries to the MPFL closer to the adductor tubercle [18,23]. Potentially there may be a role for distal or medial displacement of the tibial tuberosity for conditions such as patella alta. There is, however, a dearth of scientific reports on the results of tuberosity transfer procedures when used in isolation. Carney et al. [39] recently reported 26-year results of the Roux-Elmslie-Trilatt procedure in 14 patients. This is a "3-in-1" procedure involving lateral release, medial plication, and tuberosity transfer with, presumably, a variable contribution of each subsection of the operation to the final result. Although the re-dislocation rate remained unchanged, there was deterioration in knee function between the 3- and 26-year reviews.

Many biomechanical studies have shown that the MPFL is the main check-rein in preventing lateral patellar dislocation, providing up to 60% of the total medial restraining force [2,11,15,16,26,41]. Nomura et al. [14] have shown that isolated sectioning of the MPFL greatly increases the lateral shift of the patella during 20° to 90° of knee flexion, even with the other medial patellar stabilizers intact, while, in contrast, MPFL reconstruction can restore almost normal patellar tracking during 20° to 120° of knee flexion. Finally, MRI studies or immediate surgical exploration in knees with acute patellar dislocation have proven MPFL injury in up to 100% of the cases [8,23,31,48].

Regarding the anatomic features, most investigators agreed that the MPFL is a band-like hourglass or fan-shaped structure that runs from the medial margin of the patella to the medial femoral epicondyle showing great variation in length, thickness, and quality. Reider et al. [17] reported that the MPFL was present in only 7 (35%) of 20 dissected knees, but in most of the recent studies the MPFL was isolated in all [4,12,15,16,20,22] or more than 90% of dissected knees [6], including the present study.

There is some disagreement regarding the ligament's attachments. It has been generally accepted that the MPFL attaches to the supero-medial portion of the patella and the under-surface of the vastus medialis muscle. However, its femoral attachment has been reported to be at the ME [7,11,16], at the AT [6,22], just distal to the AT [15] at the anterior part of the ME [12,21], at the posterior part of the ME [20], and at the MCL [4]. The range of these descriptions shows that the femoral attachment of the MPFL is not a clearly identifiable feature, and the convergence of various structures and layers towards the ME probably makes it difficult to distinguish the MPFL origin. This was also true in the present study, as the average width of the femoral origin was 15.5 mm, showing a two-layered pattern with the superficial fibers of the MPFL fused with the posteromedial capsule and the deep fibers anchored just superior-posterior to the ME. We agreed with Nomura et al. [15] that the femoral attachment of the MPFL is located just distal to the AT. In addition, both Tuxoe et al. [22] and Smirk et al. [20] reported that the femoral attachment is also just distal to the AT and proximal or more posterior to the ME, respectively. This was one of the reasons why we chose to use the MIS as the pulley for the MPFL reconstruction.

The recognition of the MPFL as the main anatomic restraint for lateral patellar dislocation and the high failure rate of previously applied bony and soft-tissue procedures led many surgeons to the immediate repair of medial patellar stabilizers after acute patellar dislocation [23,31] or to subsequent reconstruction of the MPFL in patients with recurrent patellar dislocations [24–30,32–35]. Multiple techniques of MPFL reconstruction have been described in the literature, including advancement and plication of the ligament [29], medial retinaculum strip [24], quadriceps tendon graft [35], artificial mesh or polyester type ligaments [32], and hamstring tendon (ST and/or gracilis) autografts [25–28,30,33,34]. The graft is usually placed at the superior-medial border of the patella within blinded-end or through out tunnels and is fixed with heavy sutures, suture anchors, or endobutton techniques. The femoral fixation varies among authors and is accomplished with sutures, stitching of the folded tendon to itself, staples, screw-washer, and interference screws. Most authors suggest fixation of the graft with the knee in a flexed position that varies from 30° to 60°. Most of these techniques have shown acceptable results in mean subjective symptomatic improvement and low rates of recurrence in 85% to 93% of the involved cases. Despite preliminary success with MPFL reconstruction, no technique has been designed specifically to recreate the anatomy and isometry of the native ligament.

All the above-mentioned techniques represent "static" fixation of the MPFL ligament at the more recognized sites of its origin and insertion to the patella. Deie et al. [25], in contrast, proposed a more "dynamic" technique of MPFL reconstruction for the treatment of habitual or recurrent dislocation of the patella in children (4 patients, 6 knees, 2003) with the transfer of the ST tendon to the patella using the posterior third of the femoral insertion of the MCL as a pulley. In 2005 the same authors [26] reported midterm (minimum follow-up of 5 years) results of their technique in 43 patients; the MPFL reconstruction was combined with lateral release and VMO advancement in 39 of them, representing, in fact, a "3-in-1" procedure. Although the authors had no recurrence of dislocation after surgery, the lateral and medial shift ratio and the Insall-Salvati ratio remained abnormal.

Limitations

It is difficult to extrapolate our results to the entire population as our study had a small sample. The use of cadavers in the study creates a similar problem. Firstly, the age of the cadavers was much greater than those who sustain patellar dislocation (usually persons 20–30 years old). Secondly, the authors were unable to obtain fresh specimens for the study and, due to our contractual agreement with the tissue bank, were also unable to use a mounting device. Loading occurred manually at low flexion angles (0° and 30°) and through the natural tension of the intact extensor mechanism at higher flexion angles (60° and 90°). Thirdly, it is questionable whether the cadaveric patella moves in exactly the same way as in the clinical setting and whether the lack of native viscoelasticity has any significant influence on the tensile strength of the MIS and MCL pulleys.

CONCLUSIONS

The reconstruction described by Deie and our own are the only anatomic and dynamic, if not isometric, reconstructions of the MPFL. We believe that the MCL cannot play the role of a pulley to the ST graft because of the orientation of its fibers parallel to the movement axis of the patella. In our cadaveric study, the ST autograft split the MCL fibers during flexion and extension of the knee and the MCL gradually became loose. However, our data showed that the adductor's tubercle represents a slightly less isometric point than the ME. Our modification of this technique utilizes the MIS as a pulley for the ST tendon. In support of the findings of Steiner et al. [49] and on the basis of current evidence we do not believe there is a role for trochleoplasty or other bony and cartilage procedures even in the presence of dysplasia.

Our cadaveric study also confirmed the native MPFL to be a non-isometric structure. We therefore aim for a dynamic femoral fixation point close to the adductor's tubercle that does not involve excessive soft-tissue dissection or implantation or hardware at this prominent part of the femur that can lead to symptoms of its own. By avoiding a static femoral fixation point and tensioning the graft at 60–90°, we hope to avoid any potential of over-constraint of the patellofemoral joint, thereby making this reconstruction both safe and, from our preliminary data, effective. By not interfering with the pre-morbid anatomy, we hope to evaluate the results of reconstruction of the MPFL in isolation.

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