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ORIGINAL ARTICLE

Anatomy of the Medial Patello-Femoral Ligament: a systematic review of the last 20 years literature

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Abstract

Background Although many studies have investigated the anatomy of the Medial Patello-Femoral Ligament (MPFL), some studies have even questioned its existence. In the last 20 years, there is a renewed interest on the role of the MPFL in patello-femoral instability. As a result, several studies have been published that describe the anatomy, function and possible surgical reconstruction of the MPFL. Despite the large amount of literature produced, there is still a lack of consensus on what is its real anatomy as there are currently no systematic reviews on this topic.

Purposes Thus, the aim of this review is to systematically report the results in literature regarding in anatomical papers, the existence, size, insertion sites and relationships of this ligament with the other medial structures of the knee.

Methods We have systematically analyzed anatomical studies currently available in literature between 1980 and December 2012. The search was carried out on Medline, Embase, Cochrane Library and Google Scholar. We checked reference lists of articles, reviews and textbooks identified by the search strategy for other possible relevant studies.

Results The outcomes examined are the presence of the ligament, its size (length, width, thickness), and its patellar and femoral insertions. A total of 312 cadaveric knees were included in the 17 studies; the MPFL was identified in 99 % of cases (309).

Conclusions The consensus is that the MPFL is almost always present in the dissected knees. The size and insertions of the ligament demonstrate great variation between cadavers.

Level of evidence Systematic review of anatomical study, Level 1.

Keywords MPFL · Anatomy · Review · Insertion · Reconstruction

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Introduction

Although there are many studies in literature concerning the Medial Patello-Femoral Ligament (MPFL), some studies cast doubts on its existence. For example, one study by Reider et al. [15] documented its presence in only seven of the 48 knees examined.

Aragão et al. [3] in their anatomical study report that none of the volumes of the "Nomina Anatomica" nor any of the traditional anatomy textbooks mention the MPFL as a separate structure of the knee. The first to mention the MPFL in an article were Warren and Marshall [23]. They described the MPFL as part of the second layer in the intermediate strata between the joint capsule and the superficial fascia. There is a general agreement that there may be side to side differences in the same individual [7–22], but the extent of these differences does not seem dependent on the size, race or morphotype. In fact, many case series show that individuals from the same population have marked differences regarding both insertion site and the MPFL's relationship with the other medial structures of the knee [15].

In recent years, given the importance of the MPFL for the stabilization of the patella [5, 7, 13, 22], there have been numerous studies to investigate its anatomy, function and possible surgical reconstruction. Despite the extensive amount of work produced, there are no current systematic reviews. Thus, the aim of this review is to systematically report the results in literature regarding the existence, size, insertion sites and relationships of this ligament with the other medial structures of the knee.

Search strategy and criteria

Were used the following keywords: (Medial Patello-femoral Ligament) AND (Anatomy).

We searched the Cochrane Central Register of Controlled Trials (*The Cochrane Library*, Issue 3, 2005), Medline (1992 to December 2012), CINAHL (1992 to December 2012), Embase (1992 to 2012) and Google Scholar (1992 to 2012 and in the following journals: Clinical Anatomy, Journal of Anatomy, Journal of Morphology, Acta Anatomica and Annals of Anatomy.

Two reviewers (GP, MMT) independently selected the papers, initially based on title and abstract. From the title, keywords and abstract, they assessed whether the study met the inclusion criteria of the selected references; the full article was retrieved for final assessment. Next, they independently performed a final selection of the trials to be included in the review, using a standardized form. Disagreements were solved in a consensus meeting. Duplicates were deleted.

The results obtained, including published and unpublished studies, were limited to primary studies, those in English and published in the last 20 years. Only basic science level 1 studies and homogeneous papers that reported the results of measurements of the ligament on cadavers were included. Studies of reconstructive techniques, epidemiological studies, diagnostic studies or biomechanical studies were excluded.

Anatomical Outcomes were recognition rate of the MPFL (main outcome), length, width, thickness, femoral insertion, patellar insertion and relations with the other medial knee structures (capsule, muscles, vessels and nerves).

By eliminating the titles that recurred in the various search engines, the research strategy yielded 821 hits, and the majority of papers excluded were descriptions or discussions about surgical techniques or rehabilitative treatment for patella dislocation-related lesions. The articles were analyzed to see whether they could meet the criteria for inclusion. The primary studies that reported outcomes of the anatomy of MPFL at the final selection were 13 noted in the flow chart in Fig. 1.

Article founded are summarized in Table 1 according to the following information: author/year/journal; study design, level of evidence and characteristics (number of knees, mean age, sex and preparation) of specimens; existence of the ligament; technical description of the dissection; and outcomes measured.

Furthermore, we identified four additional studies bearing only the main outcome, the presence of the MPFL without further measurements. These studies have been summarized in Table 2.

The homogeneous data were analyzed by the calculation of the average and standard deviation. Descriptive analysis was conducted when data were not amenable to quantitative analysis.

Results

A total of 312 cadaveric knees were included in the 17 studies; the MPFL was identified in 99 % of cases (309). The average age at death of the cadavers is 70.15 years. The majority of the knees had belonged to males (62.8 %) and were right knees (53.2 %).

All the measurements were calculated by normalizing the average size reported in studies with the number of specimens: the average length of the MPFL was 56.9 mm (SD 4.69) with a range of 46.0–75.0 mm. The width at the middle point was 17.8 mm (SD 4.4) with a range of 8.0–30.0 mm; the patellar insertion was 26.0 mm (SD 4:53) with a range of 14.0–52.0 mm, and the femoral insertion was 12.7 mm at (SD 2.6) with a range of 6.0–28.8 mm. The patellar listing has been highlighted to 2/3 proximal in 56.9 % of cases, in 41.2 % the proximal half; in 4 cases (1.3 %), in two different studies [3–19] at the distal end; and in 4 cases (1.3 %), in a single paper [3], extended to the whole patella.

In the papers by Philippot et al. [14], Desio et al. [6] and Mochizuki et al. [10], it appears that the proximal insertion of the MPFL extends to the quadriceps tendon. Mochizuki et al. also describe the close relationship between the ligament and the aponeurosis of the vastus intermedius (VI), and a looser connection with the vastus medialis obliquus (VMO).

The femoral insertion in 29.6 % of cases was given to the adductor tubercle (AT) and in 17.8 % more extensively to the medial epicondyle of the femur (E). In 44 % of the

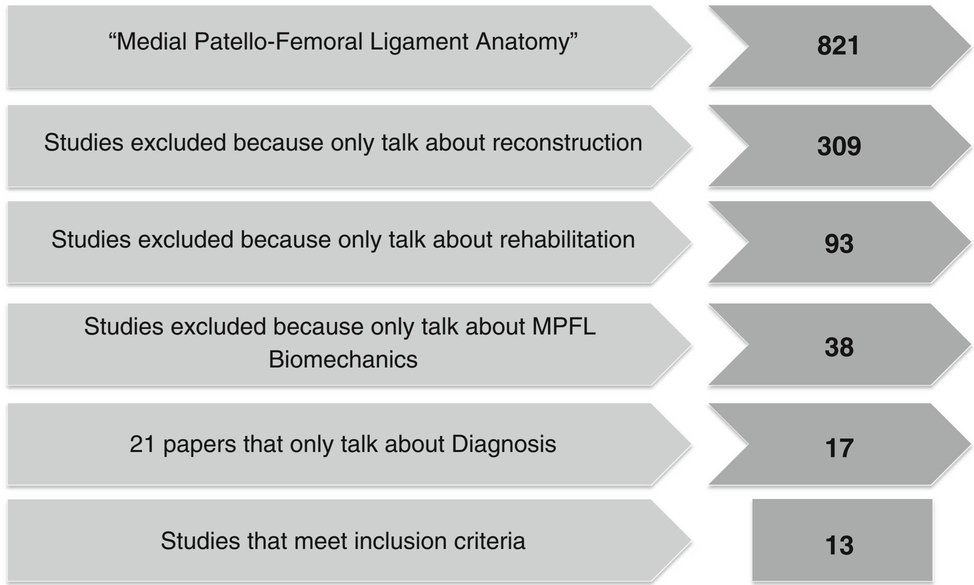

Fig. 1 Flow chart of the papers dropped by the review process

knees, a site other than the above two was described. The thickness has not been investigated much; in fact, it is reported only in Nomura's study [12] where it was found to be 0.44 ± 0.19 mm.

Close relations with the medial retinaculum (R) were identified only in 46.6 %, while in 82.5 % of the knees, a close fusion of the fibers of the VMO with the MPFL was reported.

The contact surface between VMO and MPFL was measured in two different studies: Nomura et al. [12] calculated a surface area of 20.3 ± 6.0 mm while Philippot et al. [14] measured an area of 25.7 ± 6.0 mm stating, however, that these measurements can vary greatly from person to person.

In 48.2 % of the knees, a relationship between the fibers of the superficial medial collateral ligament (MCL) and the superficial part of the MPFL was reported. In the study by Baldwin et al. [13], this structure was defined as a decussant bundle of the MPFL that occupied the entire second layer, stating that the medial retinaculum is not an independent structure (Table 3).

Discussion

The results from the analysis of the literature of the last 20 years clearly demonstrate that the MPFL is a constant and well-defined structure in the anatomy of the knee. While in the past it was said that it was a fickle structure [15], in light of our review, it would be safe to say that the MPFL is present in 99 % of knees. Its location is consistently found in all studies, in layer two as described by Warren and Marshal.

The MPFL extends from the patella to the medial condyle with a "sail type" structure; in fact, patellar insertion has a greater width than the femoral.

This may be a pivotal point for its reconstruction as it is important to recreate this anatomy.

At present, however, it has not been defined whether there are relationships to be respected for MPFL reconstruction: one study [22] calculated the ratios between the sizes of the patella and those of the MPFL, but the great variability of these relationships led the authors to conclude that it is impossible to use these ratios as a guide for the MPFL sizes in its reconstruction. It would be important to find a constant relationship that indicates more easily the size for MPFL reconstruction.

Only one study described the MPFL like an hourglass [19] or with the femoral insertion a little wider than the half of its length; this finding is interesting and it is described by many as the femoral insertion which may well have different relationships with the neighboring structures such as the MCL and the adductor tubercle.

The femoral insertion was much debated in the early studies between the 1980s to the mid 1990s; it was summarily described as inserting into the abductor tubercle or the medial femoral epicondyle. In 44.8 % of cases in subsequent studies, the actual site of insertion was located, in the majority of cases, in a dimple between the two structures and more specifically proximal and rear to the Epicondyle, distal and anterior to the adductor tubercle, known by some as "Nomura's point" [3, 9, 13, 22].

Table 1 Papers included in the inclusion criteria classified by author/year/journal; study design, Level of Evidence, characteristics (number of knees, mean age, sex, and preparation) of specimens; existence of the ligament; technical description of the dissection; outcomes measured

Study	Specimens	%	Dissection technique	Outcomes
Conlan et al. [5] Anatomical and biomechanical study Basic science 1st level of evidence	33 specimens (8 from an arthroscopic study, 25 fresh frozen) Age range 43–89 years	94 % (31 di 33)	Anterior approach, removed skin and MPFL were studied by sectioning the VMO fascia in proximal–distal direction and from femoral side to VMO an VI aponeurosis	Length: n.r. Width: 1.3 cm (range 0.8–2.5 cm) Thickness: n.r. Femoral Insertion: strictly superior to E, above the origin of the MCL Patellar Ins.: together with VMO and VI aponeurosis at patellar medial third VMO: MPFL merged in an aponeurosis Retinaculum: joined at distal margin
Tuxøe et al. [22] Anatomical study Basic science 1st level of evidence	39 knees from 21 fresh frozen cadavers No surgery, no trauma Average age 76 years, range 52–95 years NB: in 2 specimens MPFL was very thin but still distinguishable	100 %	Knee at a 20° flexion, skin and subcutaneous tissues were cut into Cutting of the first layer in correspondence with MCL. MPFL identification and measurements 14 random cases underwent isolation and staining for histological view	Length: 5.3 cm (range 4.5–6.4 cm) Width: 1.9 cm (range 1.0–3.0 cm) Thickness: n.r. Femoral Ins.: proximal to MCL distal to TA. Superficial fibers of MPFL derived from posteromedial capsule Patellar Ins.: proximal $^2/_3$ of patella VMO: deep surface merged in aponeurosis with MPFL and VI Retinaculum: inferior margin of MPFL not distinguishable in 23 % because not separable
Smirk et al. [19] Anatomical and biomechanical study Basic science 1st level of evidence	25 embalmed knees 17 cadavers Age range 66–100 years	100 %	Anterior approach respecting anatomical layers, they turned back the VMO and to expose the MPFL It had a sail or hourglasses shape. Soft tissues removed, isometric tests performed	Length: 58.3 mm (range 47.2–70.0 mm) Width: n.r. Thickness: n.r. Femoral Ins.: in 44 % it had an isolated insertion 1 cm distal from TA. In 40 %, it was inconstantly joined with MCL and TA; in 16 %, it was inserted at E Patellar Ins.: 92 % at prox $^1/_2$ of patella 8 % at distal $^1/_2$ of patella in 48 %, it joined with QT VMO: deep surface merged with MPFL Retinaculum: MPFL was joined in 92 %

Table 1 continued

Study	Specimens	%	Dissection technique	Outcomes
Steensen et al. [20] Anatomical and biomechanical study 1st level of evidence	11 fresh frozen; from 7 cadavers 7 male, 4 female No previous surgery All cadavers were old at death	100 %	Longitudinal anterior incision, using dissection scissors, MPFL was looked for	Length: n.r. Width: P 17 mm (range 14–20 mm) F 15.4 mm (range 11–20 mm) Thickness: n.r. Femoral Ins.: anterior part of E Patellar Ins.: superomedial corner of patella, 38.8 % of medial surface MCL: always in contact with distal margin of MPFL VMO: no relationship in 8 knees
Andrikoula et al. [2] Anatomical study Basic science 1st level of evidence	10 fresh frozen knees 7 male 3 female 6 right, 4 left Age range 55 years No deformity, no degenerative diseases	100 %	Skin was separated from muscular fascia and after they used a 3.5× microscope in order to separate the three parapatellar layers. Then they proceeded to identify quadriceps muscular group and their tendons With 6× and 10× microscopes they proceeded to isolate medial structures, MPFL, blood vessels and nerves	Length: 54.2 mm (range 46–64 mm; SD 6.08) Width: 20.7 mm (range 9–30 mm; SD 6.04) Thickness: n.r. Femoral Ins.: E Patellar Ins.: proximal $^2/_3$ of patella VMO: inconstant relationship with the deep surface of MPFL Retinaculum: not distinguishable from the distal margin of MPFL
Nomura et al. [12] Anatomical study Basic science 1st level of evidence	20 knees, 6 fresh frozen amputees and 14 from cadaver Some specimens had had surgical treatment or had lost soft tissue from disease Average age 65 years (range 29–78 years)	100 %	Putting a weight of 1 kg on Quadriceps Muscle for tension and facilitate MPFL identification. Anterior approach to access the anterior capsule. They removed retinacula and folded over the VMO to reveal MPFL Due to the loss of soft tissue, dissection was sometimes difficult	Length: 58.8 ± 4.7 mm; range 46–64 mm Width: 12.0 ± 3.1 mm Thickness: 0.44 ± 0.19 mm at the middle Femoral Ins.: 9.5 ± 1.8 mm proximal 5.0 ± 1.7 mm posterior to E Patellar Ins.: proximal $^2/_3$ extended to VI VMO: was joined to MPFL for 20.3 ± 6.1 mm in length at proximal side of MPFL MCL: in 50 % superficial fibers of MPFL continued in superficial fibers of MCL
Panagiotopuolos et al. [13] Biomechanical and anatomical study Basic science 1st level of evidence	8 fresh frozen knees	100 %	Removing the skin, they looked for the MPFL by cutting the medial capsule in front of the TA from the second layer Following the horizontal fibers of the ligament they isolated the MPML, the MPTL and the Retinacula. A tensiometer was attached and they carried out biomechanical tension test	Length: 47.37 mm (range 45–50 mm) Width: at femur side 14.87 mm (range 10–20 mm) at patellar side 25.25 mm (range 20–30 mm) Thickness: n.r. Femoral Ins.: in 7 cases at E, in 1 case 10 mm distal from E Patellar Ins.: medial side of patella VMO: it merged with MPFL Retinaculum: distal side of MPFL is not distinguishable from retinaculum

Table 1 continued

Study	Specimens	%	Dissection technique	Outcomes
LaPrade et al. [9] Anatomical study Basic science 1st level of evidence	8 fresh frozen Average of 59 years (range 44–72 years)	100 %	Specimens were placed on a holding station and dissected from posterior and medial side Structures were measured with an electromagnetic device by the same operator	Length: 65.2 mm (range 56.8–77.8 mm) Width: n.r. Thickness: n.r. Femoral Ins.: 3.8 mm (range 2.1–6.3 mm) distal and 1.9 mm (range 1.3–3.2 mm) anterior from TA; 10.6 mm (range of 8.0–13.4 mm) proximal and 8.8 mm (6.7–10.3 mm) posterior from E Patellar Ins.: in 41.4 % proximal part of patella MCL: superficial fibers are merged with MPFL
Aragão et al. [3] Anatomical study Basic science 1st level of evidence	17 specimens from 10 different cadavers in 10 % of formalin solution 8 right, 9 left 9 male 1 female No trauma	88 % (15 of 17)	Anterior incision from proximal 2 cm of superior margin of patella to tibial tuberosity. Then, they made two medio-lateral incisions since TA showed VMO, AM and MPFL	Length: 55.6 ± 2.9 mm (46.0–58.0 mm) Width: # 27.90 ± 6.4 mm (range 16.0–38.8 mm) at patellar side # 20.2 ± 4.7 mm (range 14.0–27.0 mm) at medial side # 17.1 ± 6.0 mm (range 10.0–28.8) at femoral side Thickness: n.r. Femoral Ins.: in 67 % the MPFL was adherent to TA, in 1 case at the E Patellar Ins.: 7 % medial $^{1}/_{3}$ of patella 13 % proximal $^{1}/_{3}$ 40 % proximal $^{2}/_{3}$ 13 % distal $^{2}/_{3}$ 27 % all medial side VMO: all the MPFL were in contact MCL: in 80 % superficial fibers were in contact with MPFL
Baldwin et al. [4] Anatomical study Basic science 1st level of evidence	50 fresh frozen (−18 °C) or fresh (3 °C) 20 female e 30 male 27 right 23 left Average age 71, years range 38–97 years no surgical treatment NB: 1 MPFL was damaged during the dissection	100 %	Anterior access, they cut skin and subcutaneous tissue on the medial side looking for cruralis fascia. Then, they passed to the second layer looking for the geniculata arterial and femoral origin of MPFL Femoral insertion was composed of two bundles, one originated from the space between TA and E, and one that originated from superficial fibers of MCL	Length: 59.8 ± 4.1 mm (50.0–75.0 mm) Width: 28.2 ± 5.6 mm (range 18.0–40.0 mm) at the patellar side 10.6 ± 2.9 mm (range 6.0–15.0) on the femoral side Thickness: n.r. Femoral Ins.: proximal from E, anterior and distal from TA. 98 % are joined with MCL Patellar Ins.: proximal $^{2}/_{3}$ VMO: joined with MPFL in an inseparable structure Retinaculum: authors say that this is an all inclusive term, they do not note a distinct structure

Table 1 continued

Study	Specimens	%	Dissection technique	Outcomes
Philippot et al. [14] Anatomical study Basic science 1st level of evidence	23 knees of which 13 fresh frozen Average age 75 years, range 69–84 No surgery 1 operator, same dissection technique	100 %	Skin and subcutaneous incision, they looked for TA and E, overturned the retinaculum, they found MPFL With knee flexed at 30°, they took measurements three times	Length: 57.7 ± 5.8 mm (47.0–65.0) Width: 24.4 ± 4.8 mm (range 17.0–52.0 mm) on patellar side 12.2 ± 2.6 mm (range 8.0–14.0) on femoral side Thickness: n.r. Femoral Ins.: 10.7 ± 3.5 mm (5.0–15.0 mm) proximal to E e 11.3 ± 5.9 mm (5.0 -19-0 mm) distal from TA Patellar Ins.: prox. $^{1}/_{3}$ extended at QT VMO: joined to MPFL for 25.7 ± 6.0 mm (19.0–38.0 mm) MCL: in 9 cases, femoral insertion was attached by superficial fibers.
Mochizuki et al. [10] Anatomical study Basic science 1st level of evidence	16 specimens in formalin 8 % and ethanol 30 % 8 cadavers, 4 female, 4 male Average age 76.5 years	100 %	Anterior incision, dissection of soft tissue above MPFL. Then, they passed into the articular side, folding back the VMO, they looked for the insertions of VI, VMO and MPFL at the patellar insertion	Length: average of 56.3 ± 5.1 mm Width: n.r. Thickness: n.r. Femoral Ins.: at E Patellar Ins.: proximal $^{2}/_{3}$ VMO: distal edge is weakly joined to MPFL VI: joined at the medial side edge of MPFL for an average of 24.3 ± 2.1 mm Retinaculum: distal edge of MPFL is closely joined

n.r. not reported, *E* medial femoral epicondyle, *AM* adductor magnus muscle, *MCL* medial collateral ligament, *VMO* vastus medialis obliquus, *QT* quadriceps tendon, *P* patellar, *VI* vastus intermedius, *TA* tubercle of adductor muscles, *F* Femoral

Table 2 Additional studies bearing only the main outcome

Study	Specimens	%	Dissection technique	Outcomes
Feller et al. [7] Anatomical study Basic science 1st level of evidence	20 cadavers: 16 in formalin, 2 fresh cadaver, 2 fresh frozen 9 pairs Age range 19–79 years	100	Anterior and medial incision, they carefully described the relationships between MPFL and other medial structures. A lateral traction of the patella facilitated MPFL recognition Note: no differences between sides in the same cadaver	Length: n.r. Width: n.r. Thickness: n.r. Femoral Ins: Anterior from E Patellar Ins.: merged with VMO at proximal ½ VMO: MPFL is attached at posteromedial part of VMO Retinaculum: distal edge of MPFL was attached
Desio et al. [6] Anatomic and biomechanical study Basic science 1st level of evidence	9 fresh frozen specimens Average age 57 ± 9 years; range 43–70 years	100	They removed skin and subcutaneous tissue. Through a 1-cm incision anterior to TA, they searched for the MPFL femoral insertion. They followed along the ligament to identify the patellar insertion	Length: n.r. Width: n.r. Thickness: n.r. Femoral Ins: at TA and E with decussant fibers at AM and MCL Patellar Ins.: proximal $^1/_3$ of patella extended at medial $^1/_3$ and QT VMO: always attached at MPFL
Hautamaa et al. [8] Biomechanical study Basic science 1st level of evidence	17 fresh frozen X-ray screening for deformity or degenerative bone disease	100	QT identification, they put it in traction and they measured the patellar lateral displacements with a dynamometer, cutting the medial structures one at a time	Length: n.r. Width: n.r. Thickness: n.r. Femoral Ins: n.r. Patellar Ins.: n.r. VMO: n.r. Retinaculum: n.r.
Zaffagnini et al. [17] Biomechanical study Basic science 1st level of evidence	6 fresh frozen 2 male, 4 female average age 50 ± 7 years no disease, no surgical treatment	100	Sovrapatellar incision of 30 cm isolating femoral and patellar insertions that were disconnected VMO and other medial soft tissues MPFL kinematics were tested with a computerized system	Length: n.r. Width: n.r. Thickness: n.r. Femoral Ins: n.r. Patellar Ins.: n.r. VMO: n.r. Retinaculum: n.r.

n.r. not reported, *E* medial femoral epicondyle, *AM* great adductor muscle, *MCL* medial collateral ligament, *VMO* vastus medialis oblique, *QT* quadriceps tendon, *P* patella, *VI* vastus intermedius, *TA* adductor tubercle, *F* femoral

An interesting anatomical description was made by Baldwin et al. especially in regards to a constant relationship of the MPFL with the bifurcation of the geniculate artery.

Firstly, this relationship allows a more certain recognition of MPFL by following the artery to its Epicondyle bifurcation: the deep articular branch passes under the MPFL irrigating the articular structures, while the superficial branch passes over the ligament irrigating the femoral part of the ligament and part of the capsule surface [14].

This particular vascularization, which does not provide direct branches to the ligament, could explain why the lesions at the nearby femoral end do not heal spontaneously [17, 18].

Many authors report that the MPFL has several relationships with other medial structures, specifically with the

Table 3 Secondary outcomes of the papers included

References	Knee	Age	% MPFL	Length	Width at middle part	Width at patellar insertion	Width at femoral Insertion	Patellar insertion	Femoral insertion	Thickness	Joined at the retinaculum	Melted with VMO	Joined at the MCL
Conlan et al. [5]	33	43–89	94 % (31)	–	13.0 (8.0–25.0)	–	–	31at Prox ½	31 at TA	–	31	31	–
Tuxøe et al. [22]	39	76 (52–95)	100 %	53.0 (45.0–64.0)	19.0 (10.0–30.0)	–	–	39 at Prox $^2/_3$	39 at TA	–	9	39	39
Smirk et al. [19]	25	66–100	100 %	58.3 (47.2–70.0)	–	–	–	23at Prox ½ 2 at Dist ½	11at OAI 10atTA 4atE	–	23	25	10
Steensen et al. [21]	11	–	100 %	–	–	17.0 (14–20)	15.4 (11.0–20.0)	38 % medial surface	11 at E	–	–	3	11
Andrikoula et al. [2]	10	55	100 %	54.2 (46.0–64.0)	20.7 (9.0–30.0)	–	–	10 at Prox $^2/_3$	10 at E	–	10	10	–
Nomura et al. [11]	20	65 (29–78)	100 %	58.8 ± 4.7(46–64)	12.0 ± 3.1	–	–	20 at Prox $^2/_3$	20 Prox-Post at E	0.44 ± 0.19	20	20	10
Panagiotopoulos et al. [13]	8	–	100 %	47.37 (45.0–50.0)	–	25.25(20.0–30.0)	14.87 (10.0–20.0)	–	7 at E 1 OAI	–	–	8	–
LaPrade et al. [9]	8	59 (44–72)	100 %	65.2 (56.8–77.8)	–	–	–	48 % medial surface	D-A at TA & P-P at E	–	8	–	8
Aragão et al. [3]	17	–	88 % (15)	55.6 ± 2.9(46.0–58.0)	20.2 (14–27)	27.9 (16.0–18.8)	17.1(10.0–28.8)	7 at Prox $^2/_3$ 2 at Dist $^1/_3$ 2 at Prox $^1/_3$ 4 medial surface	4 atOAI 10 atTA 1 atE	–	–	17	12
Baldwin et al. [4]	50	71 (38–92)	100 %	59.8 ± 4.1(50.0–75.0)	–	28.2(18.0–40.0)	10.6(6.0–15.0)	50 at Prox $^2/_3$	Prox at E & D-A at TA	–	–	50	50
Philippot et al. [14]	23	75 (69–84)	100 %	57.7 ± 5.8(47.0–65.0)	–	24.4 (17.0–52.0)	12.2 (8.0–14.0)	23at Prox ½	Prox at E & Dist at TA	–	–	23	9
Mochizuki et al. [10]	16	76.5	100 %	56.3 ± 5.1	–	–	–	16 at Prox $^2/_3$	16 at E	–	23	0	–
Feller et al. [7]	20	19–79	100 %	–	–	–	–	20 at Prox ½	20 at E	–	20	20	–
Desio et al. [6]	9	57 ± 9	100 %	–	–	–	–	9 at Prox $^2/_3$	9 at OAI	–	–	9	–
Hautamaa et al. [8]	17	–	100 %	–	–	–	–	–	–	–	–	–	–
Zaffanini et al. [24]	6	50 ± 7	100 %	–	–	–	–	–	–	–	–	–	–
Total	312	70.15	99 % (309)	56.9 (SD 4.69)	17.8 (SD 4.04)	26.0 (SD 4.53)	12.7 (SD 2.6)	56.9 % at $^2/_3$ Prox 41.2 % at ½ Prox	29.6 % at TA 44.8 % at AP 17.8 at E	0.44 ± 0.19	46.6 %	82.5 %	48.2 %

Measurements are expressed in mm, the ages in years

n.r. not reported, *E* Medial Femoral Epicondyle, *AM* adductor magnus muscle, *MCL* medial collateral ligament, *OAI* own area of insertion, P-P: *VMO* vastus medialis oblique, *QT* quadriceps tendon, *P* patellar, *Prox* proximal, *Post* posterior; DA: *VI* vastus intermedius, *TA* tubercle of adductor muscles, *F* femoral, *Dist* distal, *Ant* anterior

MCL, with which it is reported to share a lot of fibers [3, 4, 9, 11, 19, 21, 22].

Both MPFL and MCL are found in the second layer, and according to Baldwin et al., the distal part of MPFL begins from the decussating fibers of the MCL defined as the "oblique decussation of the MPFL" [14].

This is connected to the transverse MPFL at the distal half of the patella creating a structure in itself that the majority of authors define as the medial retinaculum, which is an "all inclusive" term of all structures distal to the MPFL. The retinaculum is generally described as a structure involving all three layers that blend with each other in an almost indivisible entity, especially layer one and two.

Baldwin was able to separate the different layers and describe their anatomy, but in the other studies this proved impossible, and therefore, this area has been defined by everybody as the Medial Retinaculum. LaPrade et al. said that between the retinaculum and MPFL, there is a thickening of the fibers which allows, although inseparable, the identification of two distinct structures [2, 4, 6, 7, 10, 11, 15, 22].

Instead, on the proximal side, of fundamental importance is the relationship with the VMO and its tendon. While the muscle belly runs parallel to the most medial part of MPFL, its tendon has a seamless attachment, which is described in most of the papers we found, as much as 82.5 % of the cases, as having a true fusion between the two structures.

Some reports described finding the deep fascia of the VMO within the superficial layer of the MPFL as an indivisible aponeurosis [2–4, 7, 11, 14, 23].

Only Steensen et al. [20] stated that in 8 out of 11 cases these two structures had no direct contact, while Tuxoe et al. [22], besides describing the relationship between the MPFL and VMO fibers, also observed a direct relationship between the MPFL and the tendon of the vastus intermedius.

Mochizuki states that this is an exclusive relationship that the main tendon with which the MPFL blends its fibers is the vastus intermedius, whereas relations with the VMO are only minimal [10].

As can be seen, however, from all studies, the static structure of the MPFL comes into contact with tendon structures creating an anatomical aponeurosis, which during quadriceps contraction make the entire system dynamic and hence crucial for the stability of the medial patello-femoral joint. This anatomical aponeurosis guides and pushes the patella in the trochlea during active flexion making it even more important to the integrity of the MPFL as a stabilizer. This is why some authors claim that it is desirable during reconstruction of the ligament to re-establish the relationships of continuity that exist with the VMO and the VI [10–13]. Thus, in cases where the quadriceps muscle is hypotrophic, due to lack of training or after injury, patellar instability may develop.

Furthermore, this has a clear impact on clinical practice where, in many cases, proper muscular rehabilitation leads to the resolution of the maltracking or instability symptoms. This may also in part explain why both open kinetic chain exercises in the phase immediately after injury or surgery is detrimental and why the mechanism of dislocation mainly occurs when the contraction of the quadriceps is not effective bending the knee from total extension [16].

There are still some doubts regarding the patellar insertion; in fact, in the vast majority of cases, it is on the proximal side of the patella. In the papers considered in our revision, the insertion is indicated in 56.9 % to be 2/3 proximal, and in 41.2 % to be in the proximal half. Moreover, in over 98 % of the cases, it would be a technical error to reconstruct the MPFL positioning the insertion in the distal half. The different findings on the femoral side and on the patellar side make the MPFL very variable, even in its thickness, and it is difficult, sometimes even impossible, to separate the different structures. Nomura et al. have tried to measure it reporting 0.44 ± 0.19 mm. Undoubtedly, however, these measurements vary greatly among individuals and between the patellar and femoral sides.

The histology of the MPFL, which is still not entirely clear, macroscopically resembles a tendon, but from an anatomical and biomechanical point of view, it is undoubtedly a ligament.

Tuxøe et al. have microscopically analyzed the MPFL fibers making interesting considerations concerning the presence of free nerve terminations, in this case also with many person to person variables.

Where there were many nervous fibers, the MPFL was wider, while where there were fewer fibers, it was narrower. Theoretically, the MPFL should be classified together with the other structures that regulate neuromuscular balance. A lesion of this ligament that leads to an interruption in the proprioceptive reflex arches may explain the high frequency of recurrence of dislocation in people who suffer of patellar instability.

According to Amis et al., a rupture of this structure always occurs in lateral patellar dislocation because MPFL can undergo a maximum elongation of 20–30 % (18–20 mm), and this is much less than the patellar width which often exceeds 40 mm [1, 17, 18].

A possible limitation of all the studies found in the literature concern the age of the specimens examined: a weighted average of 70.15 years is very high and includes a population that suffers, in the vast majority of cases of patellar instability. Finding young anatomic specimens is rare, and only in Feller's study [7] was there a knee of a 19 year old. However, it is hard to believe that such radical changes in the anatomy occur with advancing age.

The higher incidence of this disease at a young age is more related to increased activity and changes in visco-elasticity or bony structures rather than to the MPFL. What changes is the functionality rather than the morphology of the ligament. The same can be said for gender: the pathology of patellar instability is known to be more common in women; however, the percentage of males (62.8 %) described in the papers examined is not fully in line with this. To date, none of the authors have compared the characteristics of the female MPFL structure to that of the male.

The consensus is that the MPFL is almost always present in the dissected knees. The size and insertions of the ligament demonstrate great variation between cadavers.

It has a distinct structure: its patellar insertions, that mostly occur via an aponeurosis tissue with vastus medialis obliquus and vastus intermedius, is at the medial third of the patella, but it can be extended in some cases at the proximal third patella or at the quadriceps tendon or in rare cases at the distal third of the patella.

In the femoral side, the MPFL is inserted in its own site, in most cases distinct both from Medial Epicondyle and Adductor Tubercle, located on average at 9.5 mm distally and anteriorly in respect to the Anterior Tubercle. Its lower margin was difficult to distinguish.

Given the importance of this structure, its reconstruction is essential. Thanks to the studies performed in recent years and the increasing knowledge, the reconstructions can now be performed miming the original anatomy of the MPFL and recomposing its physiological function.

Conflict of interest Authors wish to confirm that there is no known conflict of interests associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome.

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