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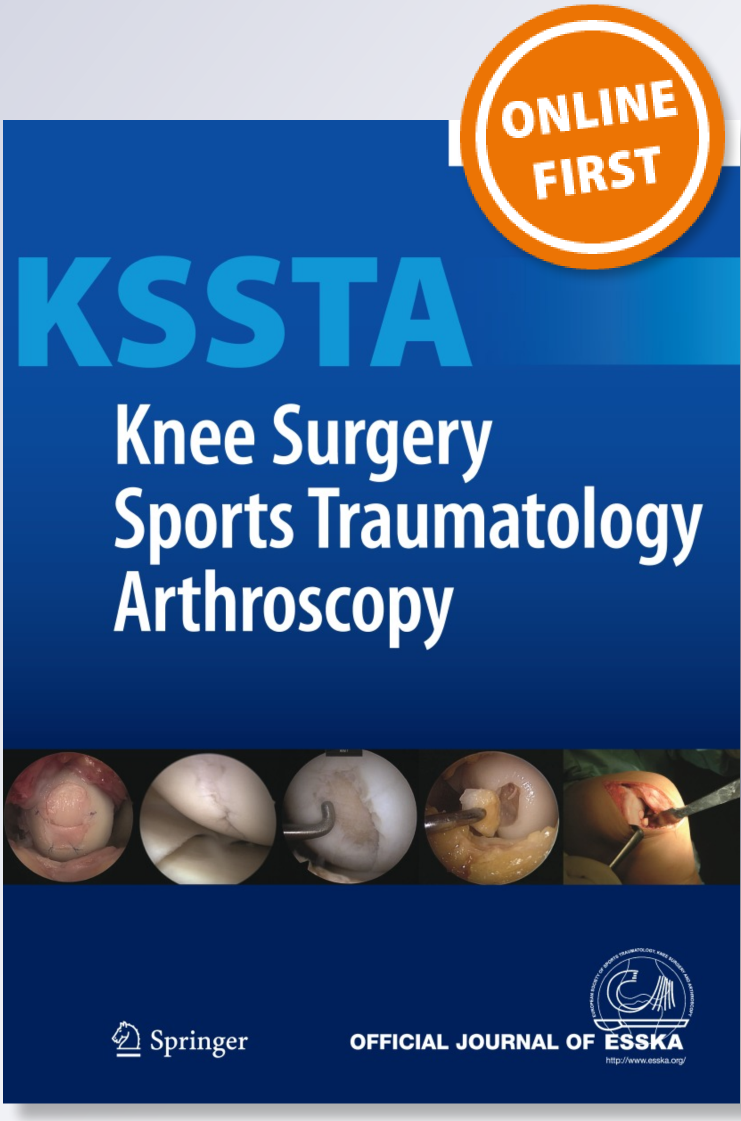

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Shape and size of the medial patellofemoral ligament for the best surgical reconstruction: a human cadaveric study

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Abstract

Purpose The aim of this study was to investigate the shape and the attachments of the medial patellofemoral ligament (MPFL) in cadaver specimens to determine an anatomical basis for the best MPFL reconstruction.

Methods Twenty fresh-frozen knees were used. Dissection protocol implied performing dissections from within the knee joint. We investigated the shape and the attachments between the MPFL and the quadriceps tendon, the patellar and femur insertions, and all the other relationships with the medial soft tissues of the knee.

Results The distal fibers of MPFL were interdigitated with the deep layer of the medial retinaculum. All isolated ligament had a sail-like shape with the patellar side bigger than the femoral side. The femoral insertion, distinct both from medial epicondyle and adductor tubercle, was located at 9.5 mm (range 4–22) distal and anterior respect to adductor tubercle and proximal and posterior to epicondyle. The medial third of the thickness of patella was involved in the insertion. The proximal third of the patella is always involved in the MPFL attachment; in 45 % of the cases, it was extended to the medial third and in one case, an extension at the distal third was found. Additionally in 35 % (7 cases), it extended to the quadriceps tendon and it were inconstantly attached at the vastus medialis obliques (VMO) tendon and at the vastus intermedius (VI) tendon in an aponeurotic structure.

Conclusions The MPFL is a distinct structure that goes from patella to femur with a sail-like shape; its patellar insertion, that mostly occur via an aponeurosis tissue with VMO and VI, is at the proximal third of the patella but it may extend in some cases to the medial third patella or to the quadriceps tendon, or very rarely to the distal third of the patella. In the femoral side, the MPFL is inserted in its own site, in most cases distinct both from epicondyle and adductor tubercle, located on average at a 9.5 mm distance distally and anteriorly in respect to the adductor tubercle. Its lower margin was difficult to define. Given the importance of this structure, it must be reconstructed as anatomically as possible in its insertion and in its shape. Many attempts have been made to make functional reconstructions with less than excellent results.

Keywords MPFL · Anatomy · Insertion · Reconstruction · Shape

Introduction

Over the past two decades, the attention of patellar instability disease has been focused on the MPFL ligament, specifically on its role as the primary medial stabilizer of the patella [13, 16, 17, 28], and the importance of its reconstruction in case of dislocation [1, 22].

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Until the 90s, however, little was known of its function, and many authors proposed the MPFL as an inconstant structure of the knee to the extent that some authors even questioned its existence [20]. In fact, even now, there is still no mention of it in any edition of the “Nomina Anatomica” [3].

In recent years, many studies have confirmed not only its function but also its constancy as a ligamentous structure of the knee [8, 12, 15, 25, 27]. It is placed in the second layer of the knee capsule, and it goes from the proximal extremity of patella to the medial part of the femur [27].

A lot of attention has been paid to understanding its extreme variability, especially at the femoral side, its anatomical relationships and especially how and when it should be reconstructed. To date, there is a lack of consensus about its anatomical limits, its size and shape; these aspects must be considered in order to reconstruct it anatomically.

The aim of this study is to investigate the MPFL’s shape, its bone attachments and soft tissue relationships, and to verify whether there are correlations between the size of the MPFL and individual anthropometrical parameters usable in surgical daily practice.

Materials and methods

Twenty fresh-frozen human knees from 19 cadavers were dissected. Eight belonged to females and 12 to males with an average age of 71.1 years (SD = 7.0); 8 were left limbs and 12 were right ones, and two came from the same person. The weight and height given refer to that at the time of death, the average weight was 62.4 kg (SD 17.6), and the average height was 167.9 cm (SD = 8.3).

No one had suffered violent deaths, not suffered injuries and none had undergone joint surgery. Not having done screening for arthritis, some knees presented some cartilage damage but none were greatly deformed and in no case were joint dynamics altered nor was there flexion–extension deficit. They ranged from the proximal third of the femur to the distal third of the leg. The Nicola’s Foundation Onlus Ethics Committee has given its approval for this study.

All dissections started with a midline incision of the skin for the entire length detaching it from the subcutaneous fascia. Through a lateral incision at the Vastus Lateralis Muscle, the dissection extended laterally at the parapatellar side and at the lateral compartment of the tibia. Thus, the joint capsule was accessed cutting proximally and distally, and detaching muscle bundles from the femur. The isolated single muscle of the quadriceps was left inserted in their distal insertions and used as landmarks.

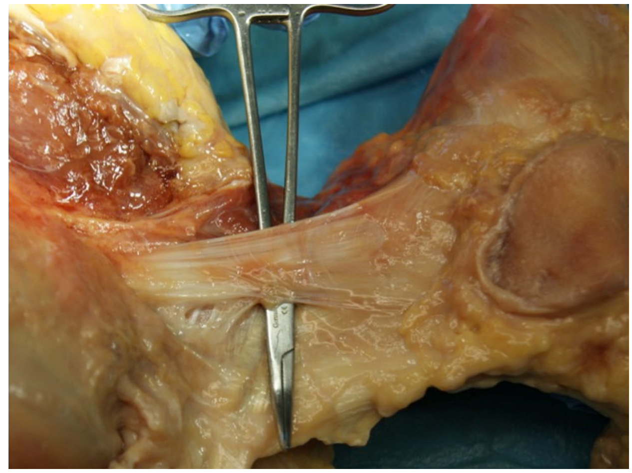

Fig. 1 MPFL seen from the inside of the knee joint. Note the proximal fibers that are inserted directly on the quadriceps tendon

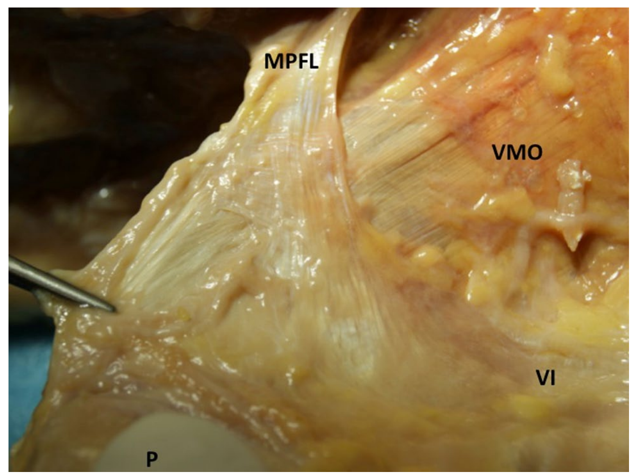

Fig. 2 Aponeurosis: the MPFL joining together to vastus medialis obliques (*VMO*) and the vastus intermedius (*VI*) directly to the patella (*P*) in the second layer of the joint capsule

The patella was then rotated and from the inside, the posteromedial capsule was opened. The third layer was thus detached isolating the synovial capsule. This way the second layer was reached quickly and safely. The fibers of the MPFL were identified by palpation and direct vision: When the patella was pulled, white fibers were observed to be straining between the patella and femur (Fig. 1).

The first layer was than detached from the outside, paying particular attention not to damage the ligament by using blunt anatomical scissors, because of the extreme adhesion commonly present between these two layers.

Each specimen was measured by three different authors using the same vernier caliper (accuracy 0.01 mm). Each author made separate and independent measurements in order to avoid any influence from the others. The reliability of these measurements was estimated with the Cronbach's alpha coefficient resulting in a range of 0.77 and 0.84.

The first measurements made during each dissection involved the insertion of the tendons of vastus medialis obliquus (VMO) and vastus intermedius (VI) on the ligament, the semiquantitative expression of its grip, depending on the difficulties encountered in detaching the first layer from the second layer. When the three structures were attached all together at the femoral insertion in an aponeurotic structure, its longitudinal dimension was measured.

Afterward were identified the medial epicondyle (E), the adductor tubercle (AT), the medial collateral ligament (MCL) insertion, the magnus adductor muscle (MAM) and the MPFL femoral insertion.

The adhesion of the VMO to MPFL was empirically quantified assigning a value between "non-adherent," "slightly adherent," "adherent" and "inseparable" and measured the length of its connections to the MPFL where present (Fig. 2).

Finally, dissection passed on the patellar side: measuring the patella's three dimensions and studying the patellar MPFL insertion to see its thickest part and how much of it was inserted.

The cases in which the insertion extended to the quadriceps tendon (QT) and those in which there was a union with the VI tendon were recorded and measured (Fig. 3).

Then, the measurements proceeded on the femoral side. The distance between epicondyle and adductor tubercle and the femoral insertion of the MPFL were measured as well as any connections with the capsule and the MCL and finally the relationships of the MPFL's distal margin (Fig. 4).

Thus, a ligament completely detached from adjacent structures was obtained which was then measured in length, width (three different measurements at the patella, femur and mid-length insertion) and, when possible, thickness, leaving it inserted at the femur and at the patella (Fig. 5).

A statistical analysis of the data was performed using the program Pad Prism 5.0 in order to determine any possible correlation between the data obtained and individual anthropometric parameters. Computed Pearson's correlation coefficient for each of the measurements was used to investigate the correlation between the MPFL ligaments and the anthropometrical parameters of each specimen. Sample size was not calculated before starting the study due to the absence of a reference range of expected correlation between MPFL sizes and anthropometrical parameters. Therefore, a post hoc power analysis was performed.

Results

The patellar dimensions were as follows: Average length from proximal to distal was 46.1 mm (SD = 4.2), while the lateral length was on average 44.2 mm (SD = 4.5), and the thickness was on an average 24.7 mm (SD = 2.5). There are no significant differences with the dimensions founded in the literature [10].

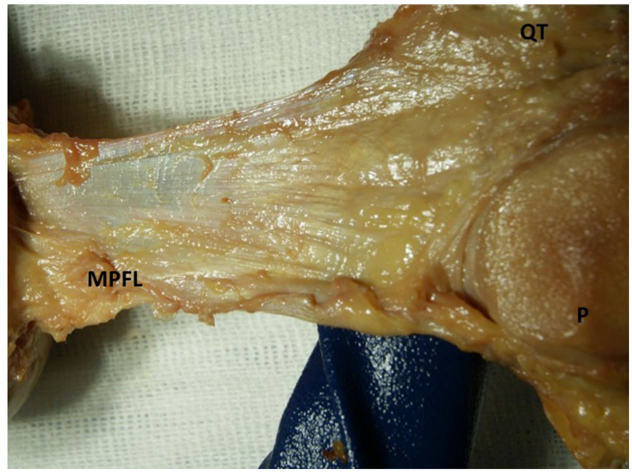

Fig. 3 Fibers of the *MPFL* have a typical type sail shape with a narrow femoral insertion that spreads like an hand fan at the patellar insertion

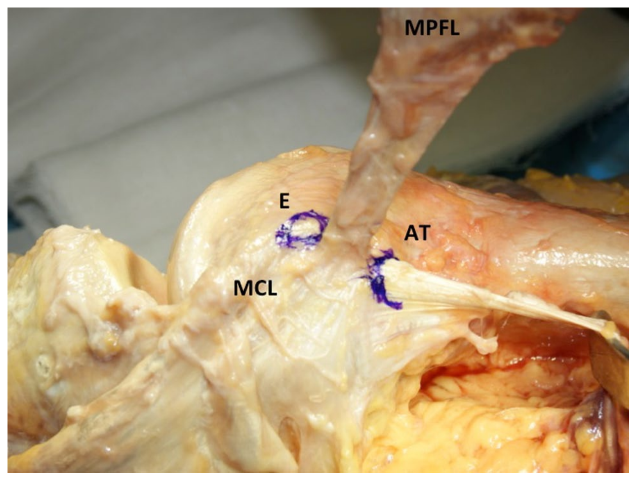

Fig. 4 Femoral insertion has its own Web site specificoche is located distal to the adductor tubercle (*AT*) and proximal to the epicondyle (*E*). Sometimes, some fibers leave directly from the medial collateral ligament (*MCL*) to the distal part of *MPFL*

For each specimen, the sagittal length of the medial condyle (SL) and the distance of the insertion of the MPFL from the anterior edge of the medial condyle (AE) were measured.

All isolated ligaments had a sail-like shape with the patellar side bigger than the femoral side. The femoral insertion, distinct both from medial epicondyle and adductor tubercle, was located at 9.5 mm (SD = 1.6) distal and anterior in respect to adductor tubercle and proximal and posterior to epicondyle.

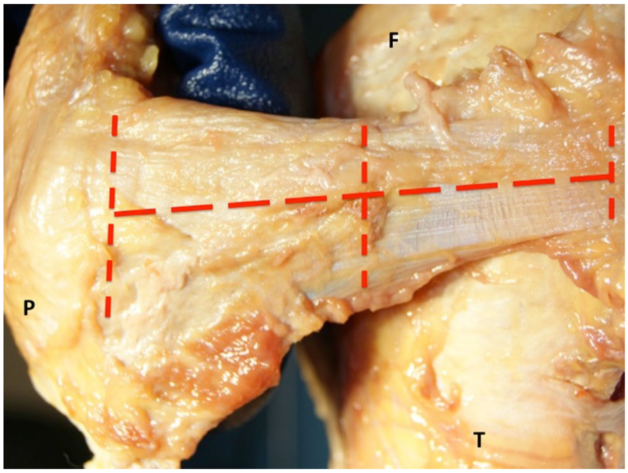

Fig. 5 Levels of measurement performed: bone-to-bone length from patella to femur and width, respectively: at the femoral insertion, at the patellar insertion and at the middle part of the ligament

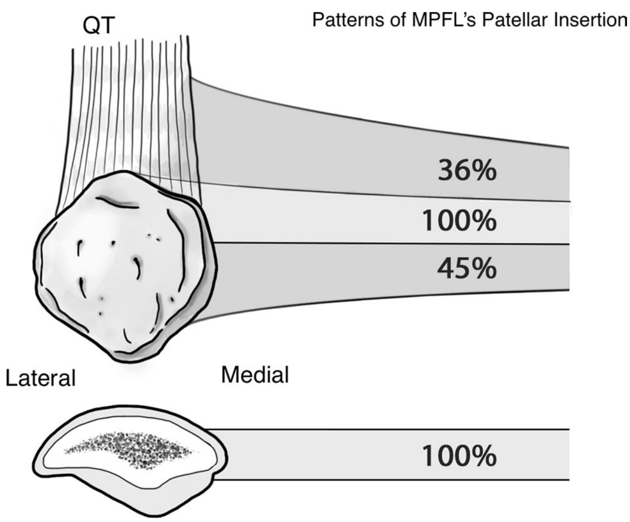

Fig. 6 Graphical representation of the patterns of MPFL insertions found in the study: In all cases, the patellar insertion occurred in the proximal third, sometimes prolonged proximally, sometimes distally

In all cases, the medial third of the thickness of patella was engaged in the insertion. The proximal third of the patella is always included in the MPFL attachment; in 11 cases, it was extended to the medial third and just in one case, it was found an extension at the distal third. Additionally in 7 cases, it extended to the quadriceps tendon (Fig. 6).

The length of the MPFL from the insertion to the femoral patellar was measured along the longest side. It had an average of 72 mm (SD = 15.6). The width was measured in three different places: Near the patella insertion, it is an average of 24.5 mm (SD = 5.2) long; halfway along the total length, it is 10.5 mm (SD = 3.40); and at the femoral insertion, 8.9 mm (SD = 3.3).

In the majority of cases, (14 specimens) MPFL merged with both VMO and VI in the aponeurosis with a surface average of 37.5 mm (SD = 6.4). While in two cases, the MPFL joined to the patella directly with an aponeurosis with the VI tendon alone; just in one case, it was totally distinct in its patellar insertion.

The thickness average was 2.07 mm at the medial patellar insertion (SD = 0.60; average thickness SD = 0.2). In the other 8 cases, it was thinner.

Statistical analysis performed using the Pearson correlation showed a direct correlation between the length of the MPFL and the thickness of the femoral insertion (Pearson $r = 0.51$; $p < 0.05$; Fig. 6a). Furthermore when measuring the approximate surface of an even sail-like geometric figure (trapezoidal) to study the correlations with the ligament's size, it was observed a direct correlation between the area and (Pearson $r = 0.67$; $p < 0.05$; Fig. 6b) length and the width of the femoral insertion, (Pearson $r = 0.64$; $p < 0.05$; Fig. 6c) and that of patella (Pearson $r = 0.74$; $p < 0.05$; Fig. 6d).

The direct correlation between the dimensions of MPFL and its area suggests that the shape remains constant despite the dimensions' variations (Fig. 7).

Discussion

The most important finding in our study is that in all the cases, MPFL had a "sail-like" shape with the patellar insertion being wider than the femoral insertion; the MPFL is a constant structure, and it is nestled within layer 2 that goes from the patella to the femoral medial condyle.

Dissection was performed from inside the joint because during the pilot studies, it was learnt that by performing the dissection from within, it was easier to isolate the MPFL without injuring it as the third layer is less adherent to the second layer than the first one, and once you are past the synovial capsule, you immediately come to the MPFL's albicans fibers.

The femur insertion was much debated in the early studies between the 80s and the mid-90s, and it was described briefly as being inserted in the adductor tubercle or medial femoral epicondyle. Subsequent studies led to the identification, in 44.8 % of cases, of its own insertion site which in the majority of cases was in a dimple between the other two structures. To be more specific, it was located proximally and distally to the epicondyle and anterior distal to the adductor tubercle, called by some "Nomura's point" [1, 4, 7, 11, 14, 18, 23].

It has also been described extensively how it has several relationships with other medial structures, specifically with

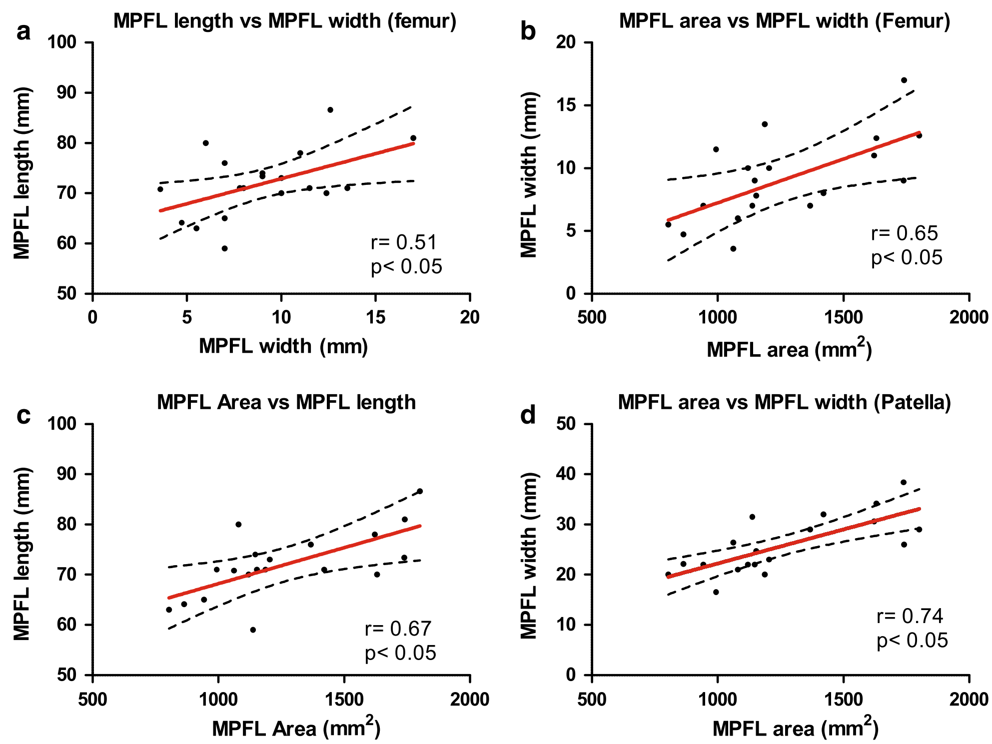

Fig. 7 Graphical representation of the statistically significant relationships founded

the MCL, with which it has been reported to have various fibers in common with the surface [1, 4, 11, 13, 17, 20, 23, 24, 26].

In a study by Baldwin et al. [4], this structure was defined as the decussate bundle of the MPFL that occupied the entire second layer, stating that the medial retinaculum is not an independent structure.

The relationships of the distal margin of the MPFL were described by almost all authors defining how there is a continuity between the MPFL and the medial retinaculum which was, in the majority of cases, indivisible [2, 5, 7, 12, 13, 23, 26].

In most cases in this study, as described previously by LaPrade et al. [11], there was a fiber thickening between the MPFL and the retinaculum, allowing two distinct structures to be identified both during patella tensioning and palpation, despite them, in almost all cases, being indissolubly attached (in only one case were the structures completely separated).

However, of paramount importance on the proximal side, are the relationships existing between the VMO and its tendon.

While the muscle belly accompanies, without direct contact, the most medial part of the ligament, its tendon has relations without solution of continuity like a true fusion between the two structures as described in most of the papers found in literature.

In some articles, it is reported that the deep fascia of the VMO has merged with the superficial layer of the MPFL in an indivisible network [1, 2, 4–6, 14, 16, 17, 23, 26].

Nomura et al. have calculated that the insertion line was of about 20.3 ± 6.0 mm, while Philippot et al. have measured it of about 25.7 ± 6.0 mm, demonstrating that these measurements vary greatly from individual to individual [13, 18].

In our study, the measurements are slightly greater, and it was found an average area of 37.5 mm at the insertion of the VMO on the MPFL; in one individual, the insertion was very high, almost 5 cm. The variables of these anatomical structures are many, especially if you take into consideration the interrelationships with the VI.

In view of the studies by Tuxoe et al. [26] that describe the relationship between the fibers of MPFL and VMO and the direct relationship with the tendon of the Vastus Intermedius, and those by Mochizuki et al. [12] who found an exclusive union between VI and MPFL, our dissections have allowed us to describe in detail the aponeurosis between the tendons of VMO, VI and the MPFL, since their fibers, which have three different directions, merge inserting at the same level and surface at the patella.

This anastomosis is activated during contraction of the quadriceps, making the whole system of fundamental importance for the stability of the medial patellofemoral joint.

The anatomical aponeurosis has been created guides and pushes the patella in the trochlea during active bending, making it very important for the integrity of the MPFL as a stabilizer [28]. This is why some authors claim that during the reconstruction of the ligament it is desirable, to re-establish the relationship of continuity that exists between the VMO and VI [12, 16].

Thus, it could be assumed that in cases where the quadriceps is hypotrophic (i.e., in the case of no training, after trauma or periods of inactivity), patellar laxity may set in.

This is clearly confirmed that in clinical practice as in many cases, correct muscle rehabilitation may lead to the resolution of maltracking or instability symptoms. This also partly explains why open kinetic chain exercises in the immediate post-injury or post-op phase are harmful to the patellofemoral articulation dislocation, and why dislocation mostly occurs in cases where there is actually a contraction of the quadriceps with the knee extended or semi-flexed [21].

The femoral insertion originates at a distinct site from both the AT and the epicondyle. This extends in an area between the two growths in a hollow which according to our measurements is 9.5 mm from the AT in a distal-anterior direction and proximal-posterior to the epicondyle.

The patellar insertion was in most cases at the medial third of the patella as described in literature, and it can extend to the second distal third in some cases and to the QT in others [3, 9, 12, 23].

To date, no patterns in size and shape (length or width) have, to our knowledge, been described to guide surgical reconstructions. In one study, the authors [26] calculated the relation between the size of the patella and that of the MPFL, but the great variability in sizes led the authors to conclude that the data could not be used as a guide for sizes in reconstruction. It would be important to find a constant proportion that indicates the right size of the MPFL for its reconstruction.

In this study was tried to correlate the ligament size with the height, weight and femoral dimensions of the cadavers using the Pearson correlation, but no correlations were found.

All it can do at present is to preserve the shape of the ligament by positioning its anterior and distal femoral insertions at the adductor tubercle and the proximal insertion at the epicondyle, and the patella insertion at the proximal third of the patella's length, in the intermediate layer of the thickness, remembering to unite it with the VI, VMO and QT tendons.

It was supposed that the smaller the patella, the more extended the patellar insertion will be: In the specimens dissected was founded only one case of total medial patellar side insertion, and it was in a very small high patella of a female subject (Fig. 8).

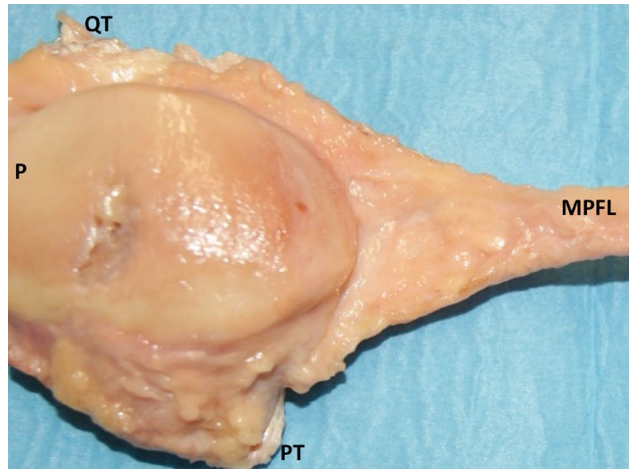

Fig. 8 Single case of insertion to the entire medial border of the patella: a female patient with very high patella

There have been a lot of difficulties in measuring the thickness of the ligament, often for fear of breaking or damaging it as it is very thin. Undoubtedly, however, the size varies greatly among individuals and between the patellar and femoral sides. Thickness has not been much investigated in the literature; in fact, it was reported in only one of Nomura's studies where it was found to be 0.44 ± 0.19 mm [14].

The Clinical Relevance of this study is that to perform an acceptable reconstruction, the basic rudiments of this structure's anatomy cannot be ignored beginning from its very shape. Reconstruction cannot be done using a single bundle, but a sail-like structure must be created with the patella attachment inserted into the intermediate thickness of the patella in order to avoid it tilting sideways which could occur when the reconstruction is performed using periosteal sutures. The femoral insertion must be placed proximal and posterior to the epicondyle, and distal and anterior to the adductor tubercles.

A possible limitation of our study is the age of the cadavers examined as it has been demonstrated that there are age-related differences in MPFL injury patterns in patellar dislocation [1, 19]. In fact in all studies, age is relatively advanced and includes a population that has not suffered, in the vast majority of cases, from patellar instability. Anatomical studies of young cadavers are rare, indeed only in one study by Feller [7] was the knee of a 19-year old described. It is hard to believe that anatomy evolves so radically with age as to create an entirely new structure. It is more plausible to presume that the higher incidence of patellar instability at a young age is related to increased activity or to changes in the elasticity of the soft tissue or bony structures following degenerative diseases in the elderly, rather than to the MPFL's anatomy.

Conclusion

Given the importance of this structure, it must be reconstructed as anatomically as possible. Many attempts have been made to make functional reconstructions with less than excellent results.

The MPFL is a distinct structure: Easily dissected from within of the knee joint, it goes from patella to femur with a sail-like shape; its patellar insertion, that mostly occur via an aponeurosis tissue with VMO and VI, is at the proximal third of the patella but it may extend in some cases to the medial third patella or to the quadriceps tendon, or very rarely to the distal third of the patella.

In the femoral side, the MPFL is inserted in its own site, in most cases distinct both from epicondyle and adductor tubercle, located on average at a 9.5 mm distance distally and anteriorly in respect to the adductor tubercle. Its lower margin was difficult to define.

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