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ORIGINAL ARTICLE

Descriptive and dynamic study of the medial patellofemoral ligament (MPFL)

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Abstract

Purpose The goal of this study was to evaluate the anatomy of the medial patellar retinaculum and the medial patellofemoral ligament (MPFL) to provide an anatomical validation of a pediatric reconstruction technique.

Methods Fifteen knees were dissected to study the MPFL and its relationship with the medial patellar retinaculum and the femoral insertion of the medial collateral ligament (MCL). The distances between the insertions of the MPFL of eight knees, and the patellar insertion of the MPFL and the femoral insertion of the MCL of four knees, were measured during the flexion to evaluate the isometricity of the native and reconstructed MPFL.

Results The medial patellar retinaculum includes four structures: the fascia, fibrous expansions of the vastus muscles, the MPFL and the medial patellomeniscal ligament. The femoral insertion of the MPFL was located just behind the femoral insertion of the MCL in 12 knees. During flexion, the distance between the insertion on the upper patella and the femoral insertion of the MPFL increased while the distance between the insertion on the lower patella and the femoral insertion of the MPFL decreased. The variation in the distances measured during the flexion was greater between the MPFL insertions ($n_{sup} = 6.5$ mm, $n_{inf} = 6.5$ mm) than between the patellar insertion of the MPFL and the femoral insertion of the MCL ($n'_{sup} = 2.5$ mm, $n'_{inf} = 5.75$ mm).

Conclusion The MPFL is not isometric. Even though the results were obtained from knees of elderly specimens, this study demonstrates reconstruction of the MPFL should take into account its anatomy and biomechanical role in the knee.

Keywords Medial patellofemoral ligament · MPFL · Patellar retinaculum

Introduction

The patella, a sesamoid bone whose role is to optimize the action of the quadriceps, is the key element of the extensor apparatus. During its course against the femoral trochlea, it undergoes numerous stresses, in particular lateral translation. Indeed, quadriceps contraction is classically responsible for a lateral Q-angle force with a tendency to cause lateral patellar dislocation [18].

The medial patellar retinaculum, and the MPFL in particular, is one of the stabilizing structures of the patella. It contributes to compensate for the lateral dislocating force during flexion and extension of the knee.

At present, MPFL reconstruction is the most frequent surgical method used to treat patellar instability. The point of femoral fixation is chosen according to the criteria described by Schöttle [15] to obtain optimal isometry and reduce the risk of stiffness or pain during flexion. In children, this isometric point is located at the growth cartilage of the distal femur in the perichondral bone. Creating a bone tunnel at this level creates a risk of injury to the growth cartilage and the need for secondary epiphysiodesis.

Thus, Chotel [4] adapted the surgical technique in children based on the method described by Chassaing [3] to preserve the growth cartilage: femoral fixation of the graft is obtained in the soft tissue, through the posterior aspect of the femoral insertion of the medial collateral ligament (MCL). These recent surgical techniques need to be validated anatomically.

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The main goal of this study was to evaluate the anatomy of the MPFL, in particular at its point of femoral insertion and its relationship to the proximal femoral insertion of the MCL. The secondary aim was to appreciate the isometry of the MPFL.

Materials and methods

This anatomical study was performed at the Nantes Anatomy Laboratory. Fifteen fresh cadaveric right knees were dissected for the study. Subjects were a mean 85 years and 3 months old. Inclusion criterion was fresh cadavers. Exclusion criteria were the presence of a scar on the inside of the right knee, morbid obesity, severe patellofemoral joint osteoarthritis and a severe hip-knee-ankle defect such as severe varus or valgus deformity secondary to knee osteoarthritis, limb length asymmetry. Dissections were performed by two surgeons: a pediatric orthopedic surgeon and a resident who is also an anatomy teacher.

Descriptive study of the medial patellar retinaculum

An anteromedial approach was taken, exposing the anterior aspect of the quadriceps and the patellar ligament. The subcutaneous tissue was pulled away from the fascial layer to the medial side of the knee, behind the adductor magnus tendon. Dissection was then performed from the superficial to the deep layers. The most medial and posterior part of the vastus medialis muscle was retracted forward, exposing the MPFL with no risk of injury. The dimensions of the MPFL, as well as the relationships between the femoral insertion of the MPFL, the femoral insertion of the MCL and the adductor tubercle were studied. Morphometric data were measured with a graduated ruler (Wilmart, ZI Les portes du Nord, 62820 LIBERCOURT, France). The measurements are described in Fig. 1 and have been reported in Table 1 in Appendix 1.

Isometricity of the MPFL

Eight MPFL were measured in eight right knees at different degrees of flexion (from 0° to 130°, 10° intervals) (Fig. 2a). The knee flexion was performed using a goniometer. On the knee in profile, the degrees of flexion were established using the diaphysis of femur and tibia benchmarks. At each degree of flexion, two measurements were taken: the distance between the point of insertion on the upper patella and the femoral insertion of the MPFL (called "SF") and the distance between the point of insertion on the lower patella and the femoral insertion of the MPFL (called "IF") (Fig. 2b). The reference distance was that of the knee in extension (SF (0°) and IF (0°), respectively). For each degree of flexion, the difference between the distance measured and the

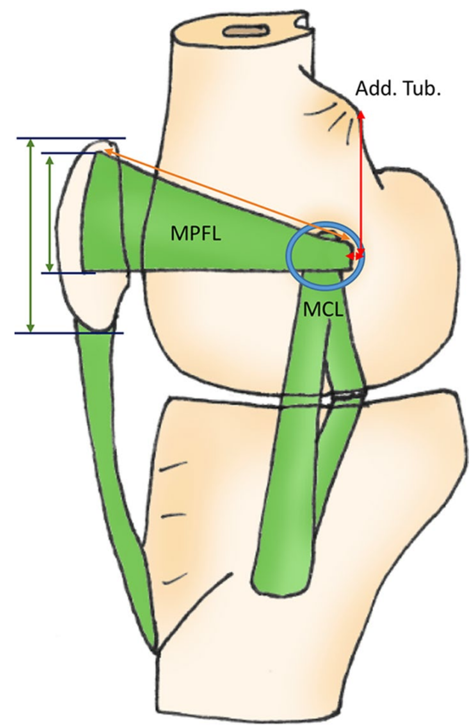


Fig. 1 Medial view: descriptive study. Length of the upper border MPFL (orange arrow), dimensions of the patella and of the patellar insertion of the MPFL (green arrows), relationships between the femoral insertion of the MPFL and the femoral insertion of the MCL (blue circle) and distance between femoral insertion of the MPFL and the adductor tubercle were studied. *MPFL* medial patella femoral ligament, *MCL* medial collateral ligament, *add. tub.* adductor tubercle (color figure online)

distance of the knee in extension was calculated. Finally, the range of differences was calculated for each knee to evaluate the variations in distance between the point of insertion on the patella and the femoral point of insertion of the MPFL during flexion.

In a second part of the study two other measurements were obtained at different degrees of flexion in four knees: the distance between the point of insertion of the MPFL on the upper patella and the point "L" (called "SL") and the distance between the point of insertion of the MPFL on the lower patella and the point "L" (called "IL") (Fig. 2b). The point "L" was precisely defined as being located at the posterior portion of the MCL, just below the proximal femoral insertion of the MCL. These two measurements corresponded to the distances between the points of insertion of a graft for MPFL reconstruction according to the pediatric Chotel technique. The reference distance was that of the knee in extension [SL (0°) and IL (0°), respectively]. Ranges and variations in distance during flexion were calculated as previously described. The measurements were performed with the help of reference guide wires and clamps. The tables, calculations and graphs were performed on Excel

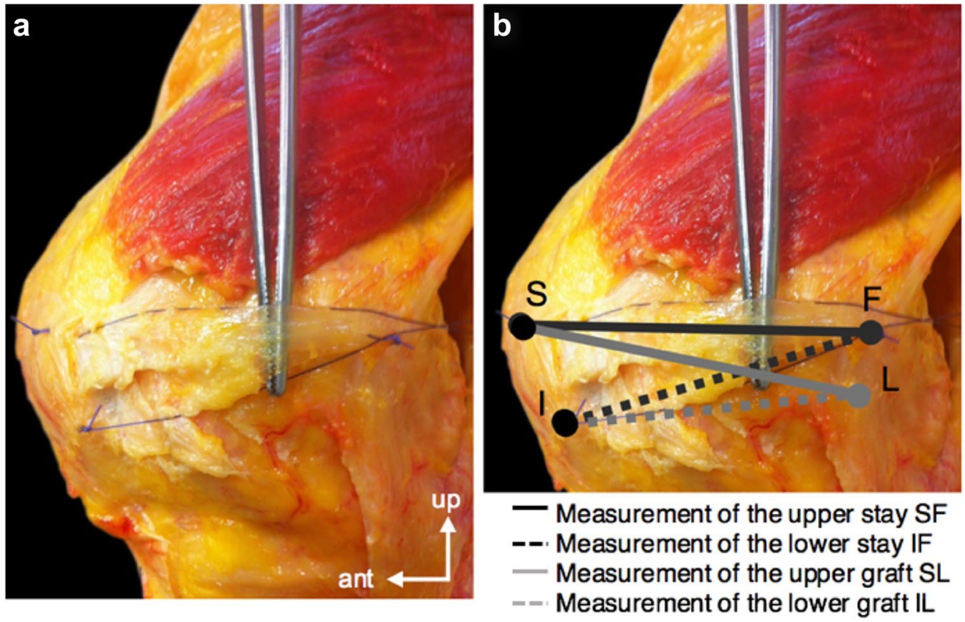


Fig. 2 Isometricity of the MPFL. **a** Methods of measurement with reference guide wires. **b** Measurement of the upper section of the MPFL (SF) then the lower section of the MPFL (IF), and the measurement between the insertion of the MPFL on the upper patella and the point "L" (SL) then between the insertion of the MPFL on the lower patella and the point "L" (IL) The point "L" was precisely defined as being located at the posterior portion of the MCL, just below the proximal femoral insertion of the MCL

(Microsoft, Redmond, WA, USA). The degree of flexion was determined with a goniometer (Robé Médical, Saint Etienne es Remiremont, France).

Results

The medial patellar retinaculum

The lateral and medial retinacula are two fibrous structures located around the patella. The medial retinaculum was much larger than its lateral counterpart. In our study, the medial retinaculum included four structures in three successive layers:

The fascial layer

The fascial layer corresponds to the junction of the fascia lata and the fascia crural. It is subcutaneous. At the level of the thigh, the fascia lata is thicker laterally (iliotibial band). It included two structures: one in front containing the sartorius muscle, and one inside containing the gracilis muscle. The fascial layer was separated from the patella by a peripatellar bursa. The fascia crural was very thick at the level of the leg (Fig. 3a).

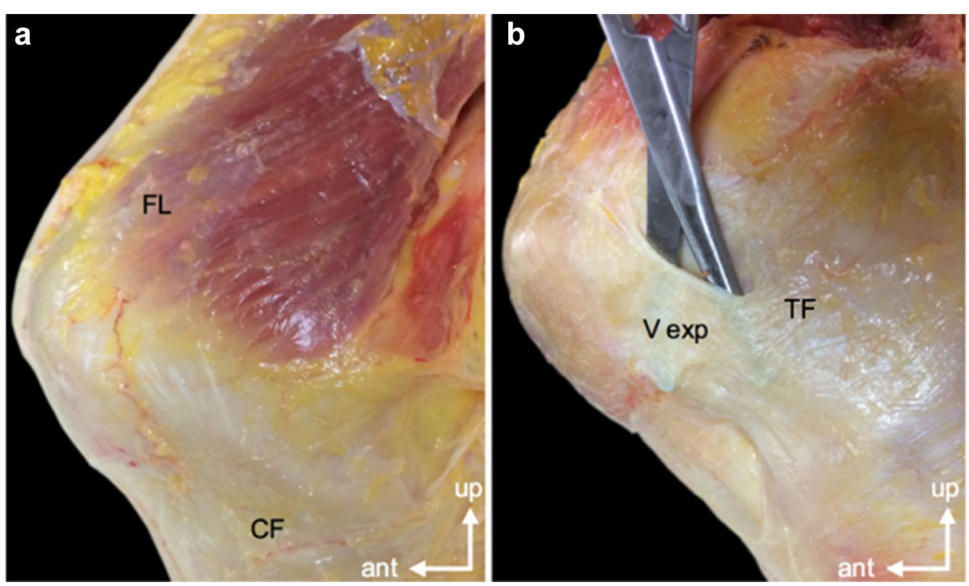


Fig. 3 Anatomy of the medial patellar retinaculum **a** the fascial layer. **b** The fibrous expansions of the vastus muscles. *FL* fascia lata, *CF* crural fascia, *V exp* fibrous expansions of the vastus muscles, *TF* transversal fibers

The fibrous expansions of the vastus muscles

Below the fascial layer were the fibrous expansions of the vastus muscles which are part of the attachment complex of the quadriceps. This thick structure included the ipsilateral expansions of the vastus medialis and the contralateral expansions of the vastus lateralis. These fibers extended downwards and inwards for insertion on the oblique border of the medial tibial condyle (Fig. 3b). The presence of transversal fibers was observed on the lower part of these fibrous expansions, which could not be separated during dissection.

The medial patellomeniscal ligament (MPML) and the medial patellofemoral ligament (MPFL)

These two structures compose the third layer of the medial patellar retinaculum. The MPML was a thin ligament that is difficult to identify. It shared the same patellar insertion as the MPFL. It then extended downwards and outwards to terminate on the anterior horn of the medial meniscus and the tibia (Fig. 4). It was mainly in contact with: the MPFL above, the expansions of the vastus muscle group, superficially, the joint capsule on a deep level, the patellar ligament externally and the medial collateral ligament internally. Although the medial patellotibial ligament has been described in other studies, it was not found in our dissections [5, 12].

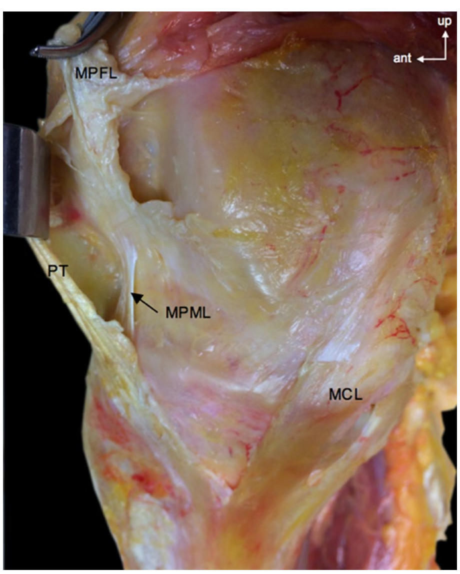


Fig. 4 The medial patellomeniscal ligament (MPML). The patellar tendon is pulled forwards and the MPFL is detached and retracted forward. *MPML* medial patellomeniscal ligament, *MPFL* medial patellofemoral ligament, *MCL* medial collateral ligament, *PT* patellar tendon

The medial patellofemoral ligament: MPFL

The MPFL is a main element of the medial patellar retinaculum. Although it was sometimes in poor condition, the MPFL was found in all our dissections. Its trapezoidal shape was comparable to a brace that anchors the patella to the femur (Fig. 5). The largest base is inserted on the patella, while the thinner base inserted on the medial femoral condyle. The upper edge was usually well defined and measured a mean 64.5 mm (min 55 mm; max 75 mm). The lower edge was sometimes difficult to identify.

Patellar insertion

The patellar insertion of the MPFL was difficult to clearly identify, as the patellar insertions of the vastus medialis, the MPFL and the MPML are shared. Our dissections tended to show that the insertion of the MPFL involved nearly three-fourth of the upper patella (ratio 0.71) (Appendix 1).

Femoral insertion

The femoral insertion was easier to identify. The MPFL was inserted on the medial femoral epicondyle, immediately behind the femoral insertion of the MCL in 80% of the cases (12 knees) (Fig. 6), remaining below and in front, at a distance from the adductor tubercle. The MPFL was inserted on the femoral insertion of the MCL in 14% of cases (two knees) in front of the femoral insertion of the MCL in 6% of cases (one knee).

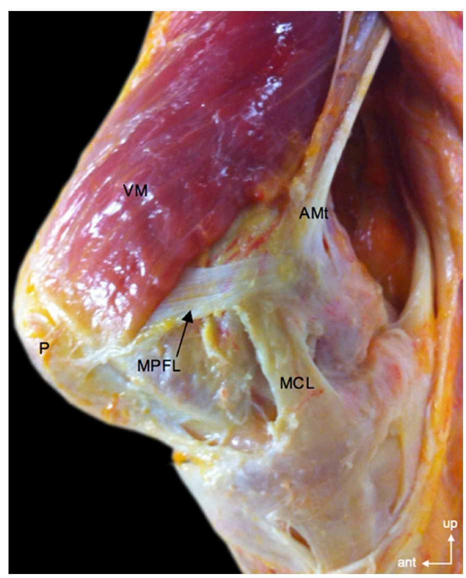


Fig. 5 Anatomy of the MPFL: overview. *MPFL* medial patellofemoral ligament, *MCL* medial collateral ligament, *VM* vastus medialis, *AMt* tendon of the adductor magnus, *P* patella

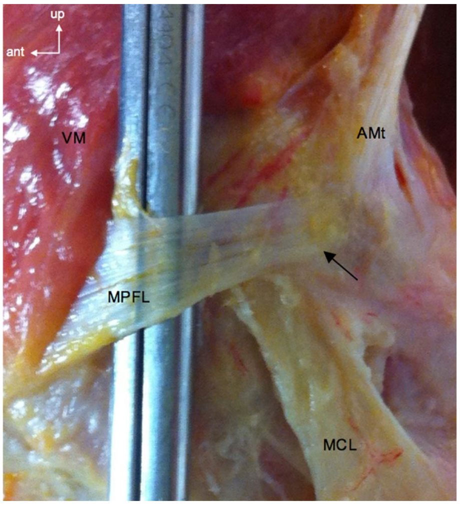


Fig. 6 Femoral insertion of the MPFL. The arrow shows the femoral insertion of the MPFL just behind the femoral insertion of the MCL in 80% of the cases. *MPFL* medial patellofemoral ligament, *MCL* medial collateral ligament, *AMt* adductor magnus tendon, *VM* vastus medialis

Main anatomical relationships of the MPFL

As described above, the fibrous expansions of the vastus muscles covered the MPFL. The vastus medialis covered the patellar insertion of the MPFL with oblique and horizontal muscular fibers. This section of the muscle is called the vastus medialis obliquus (VMO). The expansions of the MPFL extended to the deep portion of the vastus medialis (Fig. 7a). The femoral insertion of the MPFL was found a mean 8.7 mm below and 3.6 mm in front of the adductor tubercle.

The MCL was closely connected to the MPFL. It included two bundles of fibers. Superficial tibiofemoral fibers that insert on the medial femoral epicondyle then extend downwards and in front to terminate on the tibia under the insertions of the pes aserinus. The deep layer includes three types of fibers: deep femoromeniscal fibers, tibiomeniscal fibers and tibiotibial fibers covering the reflected tendon of the semimembranosus muscle (Fig. 7b).

MPFL isometricity

Native MPFL isometry was studied in eight knees. The distance between the patellar insertion and the femoral insertion was measured at different degrees of knee flexion and subtracted from the reference distance of the knee in extension. The range of the different measurements was used to evaluate the variation in the distance between the point of patellar insertion and the point of femoral insertion of the MPFL during flexion.

The upper MPFL (SF)

The distance between the insertion on the upper patella and the femoral insertion of the MPFL increased during knee flexion (Fig. 8). The mean change in length throughout knee flexion was $n_{sup} = 6.5$ mm. The distance between the patellar insertion and femoral insertion seemed to decrease from 0 to 20° of flexion.

The lower MPFL (IF)

The distance between the insertion on the lower patella and the femoral insertion of the MPFL decreased during

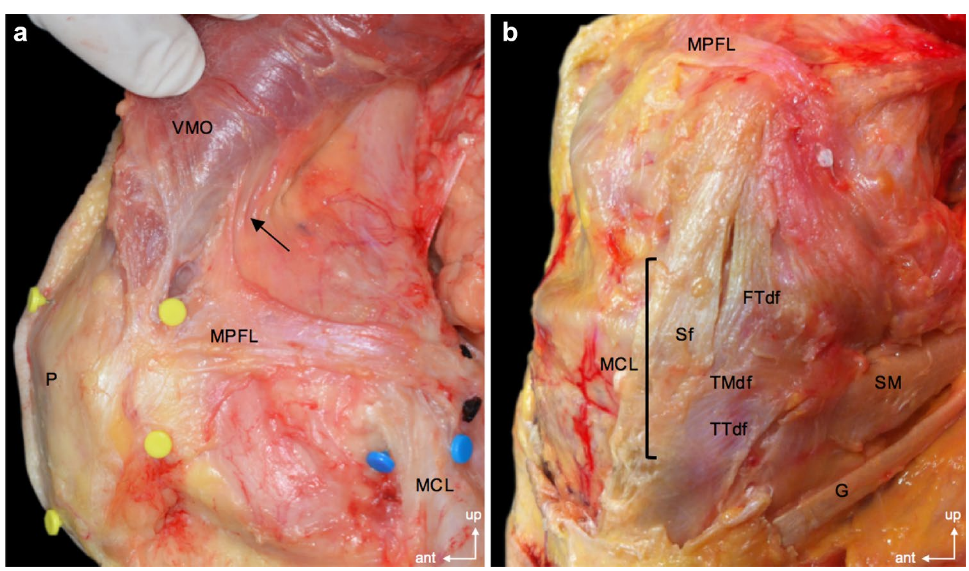
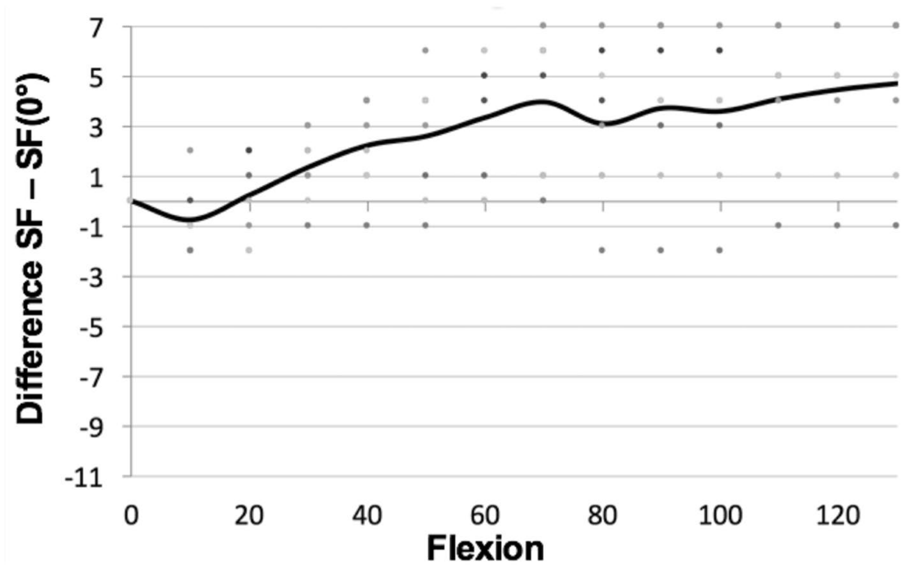


Fig. 7 Anatomical relationships with the MPFL. **a** The vastus medialis obliquus retracted upwards which covers the patellar insertion of the MPFL. The arrow shows the fibrous expansions of the MPFL that insert on the deep vastus medialis. **b** The medial collateral ligament. *MPFL* medial patellofemoral ligament, *VMO* vastus medialis obliquus, *P* patella, *MCL* medial collateral ligament, *Sf* superficial fibers, *FTdf* femorotibial deep fibers, *TMdf* tibiomeniscal deep fibers, *TTdf* tibiotibial deep fiber, *SM* semimembranosus, *G* gracilis

a



b

Knee	SF (0°)	Angle 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	Range (mm)
1	**72**	0	0	2	3	4	4	4	5	4	7	6	5	8	8	**8**
2	**60**	0	2	2	3	3	3	5	6	3	4	4	4	4	4	**6**
3	**59**	0	-1	1	1	1	1	1	1	1	3	3	5	5	7	**8**
4	**59**	0	-2	2	2	4	4	5	6	6	6	6	7	7	7	**9**
5	**59**	0	-2	-2	-1	-1	-1	0	0	-2	-2	-2	-1	-1	-1	**2**
6	**73**	0	-1	0	2	2	0	0	1	1	1	1	1	1	1	**3**
7	**68**	0	-1	-1	1	4	6	6	7	7	7	7	7	7	7	**8**
8	**55**	0	-1	-2	0	1	4	6	6	5	4	4	5	5	5	**8**
															Average of range :	**6,5**

Fig. 8 **a** Graph showing the difference "SF–SF(0°)" depending on the degree of knee flexion. The black curve shows the trend: the distance between the insertion on the upper patella and the femoral insertion of the MPFL increased during flexion. **b** Table showing the differences "SF-SF(0°)" for each degree of knee flexion. During flexion, the mean change in length throughout knee flexion between the insertion on the upper patella and the femoral insertion of the MPFL was 6.5 mm

knee flexion (Fig. 9). The mean change in length throughout knee flexion was $n_{\mathrm{inf}} = 6.5$ mm.

Study of the distances between the patellar insertions of the MPFL and the posterior aspect of the femoral insertion of the MCL

The distances between the insertion of the MPFL on the upper patella and the posterior aspect of the femoral insertion of the MCL (SL) and between the insertion of the MPFL on the lower patella and the posterior aspect of the femoral insertion of the MCL (IL) were measured at different degrees of knee flexion. These measurements were performed in four knees. The goal of this final step was to compare these measurements with the previous measurements and thus the native MPFL with a MPFL reconstruction by the Chotel pediatric technique, in which the graft is fixed to the femur by attaching it to the posterior aspect of the femoral insertion of the MCL.

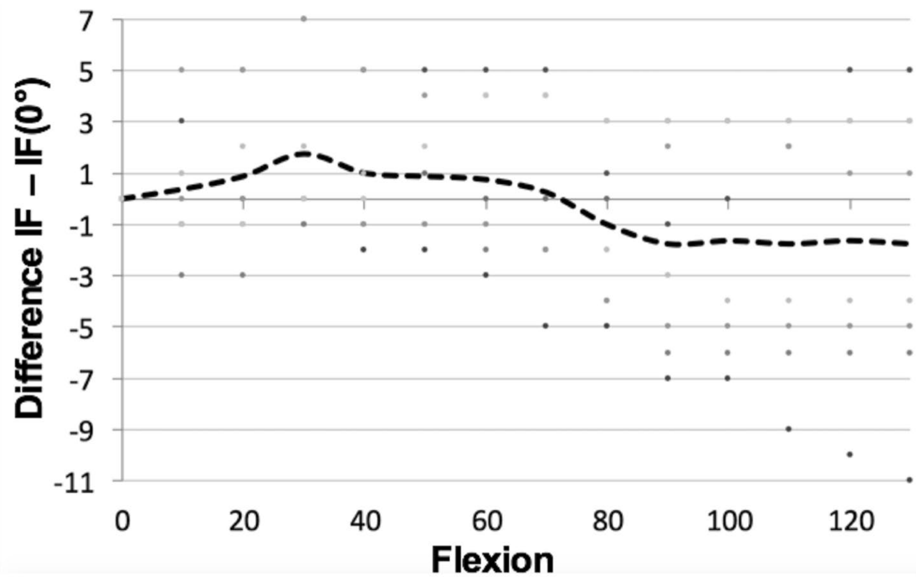
The distance of SL

The distance of SL between the insertion of the MPFL on the upper patella and the posterior aspect of the femoral insertion of the LCM increased during flexion in 50% and decreased in 50% (Fig. 10). The mean change in length throughout knee flexion was $n'_{\mathrm{sup}} = 2.5$ mm.

The distance of IL

The distance IL between the insertion of the lower patella on the MPFL and the posterior aspect of the femoral insertion of the MCL increased during flexion in 50% and decreased in 50% (Fig. 11). The mean change in length throughout knee flexion was $n'_{\mathrm{inf}} = 5.75$ mm.

Thus, there was less variation in length between the point of the patellar insertion of the MPFL and the posterior aspect of the femoral insertion of the MCL, which corresponds to the points of insertion of an MPFL reconstruction by the pediatric Chotel technique ($n'_{\mathrm{sup}} = 2.5$ mm,



a

Knee	IF (0°)	Angle 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	Range (mm)
1	**75**	0	3	5	7	5	5	5	5	1	-1	0	2	5	5	**8**
2	**55**	0	5	5	7	5	4	4	4	3	2	3	2	1	1	**7**
3	**65**	0	-1	-1	-1	1	1	0	0	0	3	3	3	3	3	**4**
4	**74**	0	-1	0	0	-2	-2	-3	-5	-5	-7	-7	-9	-10	-11	**11**
5	**58**	0	-3	-3	-1	-1	-1	-2	-2	-4	-6	-6	-6	-6	-6	**6**
6	**78**	0	1	2	2	1	-1	-1	-2	-2	-3	-4	-4	-4	-4	**6**
7	**70**	0	0	0	0	-1	-1	-1	-2	-4	-5	-5	-5	-5	-5	**5**
8	**55**	0	-1	-1	0	0	2	4	4	3	3	3	3	3	3	**5**
															Average of range :	**6,5**

b

Fig. 9 **a** Graph representing the difference "IF–IF(0°)" according to the degree of flexion. Black dotted curve shows the trend: the distance between the insertion on the lower patella and the femoral insertion of the MPFL decreased during flexion. **b** Table showing the differences "IF–IF (0°)" for each degree of flexion. During flexion, the mean change in length throughout knee flexion between the insertion on the lower patella and the femoral insertion of the MPFL was 6.5 mm

$n'_{inf} = 5.75$ mm) than the variation in length between the patellar and femoral insertions of the native MPFL ($n_{sup} = 6.5$ mm, $n_{inf} = 6.5$ mm). The graph shows the four trend curves (Fig. 12).

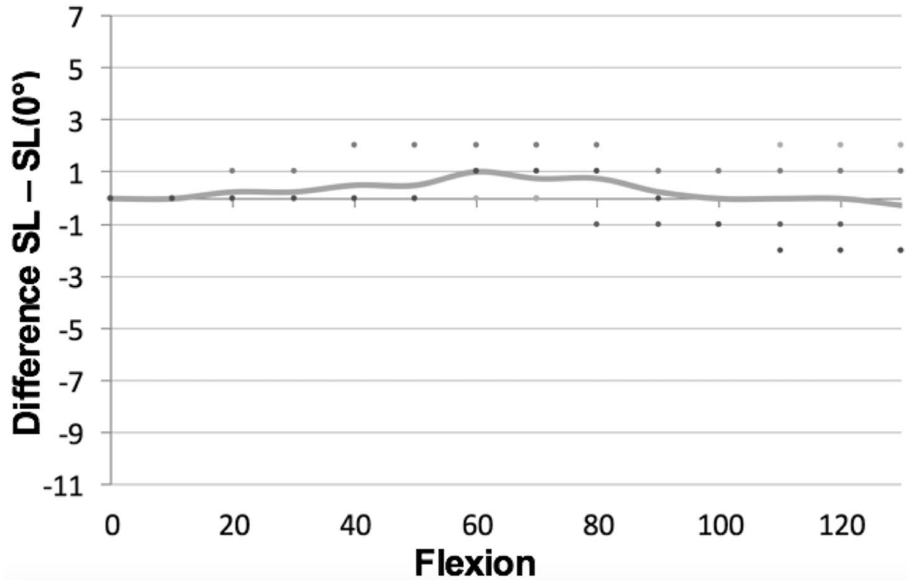
Discussion

In 1979, Warren et Marshall [20] showed that the medial patellar retinaculum was composed of three layers. The most superficial layer corresponded to the fibrous expansions of the vastus muscle group. The middle layer included the MPFL and the superficial fascia of the MCL. The deepest layer included the MPML and the deep fibrous bundle of the MCL. Our descriptive study in 15 fresh cadaveric knees confirmed that the structure of the medial patellar retinaculum was similar to that described by Warren et Marshall. In our study, the most superficial layer included the fascia, the second layer corresponded to the fibrous expansions of the vastus muscles, the third and deepest layer to the MPFL and the MPML. We did not consider the MCL to be an element of the medial patellar retinaculum.

The MPFL is a major element of the medial patellar retinaculum. In our dissections, the MPFL was found to be a trapezoid ligament that inserts on the upper three-fourth of the medial border of the patella and terminates on the medial femoral condyle. Some studies have described the femoral insertion of the MPFL [6, 8, 11, 16, 17, 19]. The medial femoral epicondyle has been widely used as the landmark to locate the femoral insertion of the MPFL [8, 11] and is classically used as the MPFL reconstruction. The studies by Smirk et al. and Fujino et al. did not identify any precise, consistent point of femoral insertion [6, 16]. They describe an "area of insertion" that includes the medial epicondyle in the center. The adductor tubercle is located in the cranial part of the area of insertion, the femoral insertion of the LCM in the caudal section, while the femoral insertion of the MPFL is located in the posterior section [16]. Aframian et al. performed a review of the literature in 2016 of 67 anatomical studies and described

Fig. 10 **a** Graph showing the difference "SL–SL(0°)" depending on the degree of flexion. The gray curve shows the trend. **b** Table showing the differences "SL–SL(0°)" for each degree of flexion. During flexion, the mean change in length throughout knee flexion between the insertion on the upper patella and the posterior aspect of the femoral insertion of the MCL was 2.5 mm

a



b

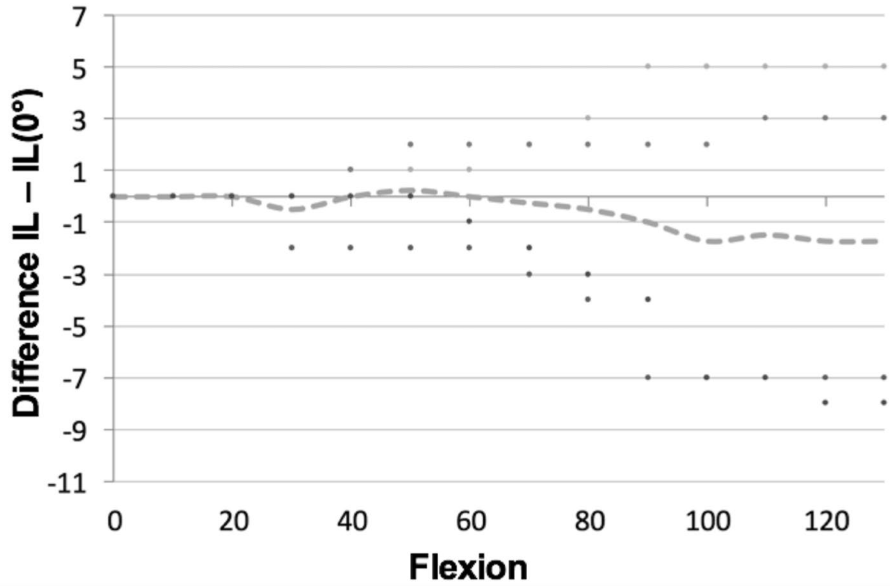
		Angle														
Knee	SL (0°)	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	Range (mm)
1	55	0	0	0	0	0	0	1	0	-1	-1	-1	-1	-1	-2	3
2	70	0	0	0	0	0	0	0	0	1	1	1	2	2	2	2
3	65	0	0	1	1	2	2	2	2	2	1	1	1	1	1	2
4	54	0	0	0	0	0	0	1	1	1	0	-1	-2	-2	-2	3
															Average of range :	2,5

a femoral area of insertion located between the medial epicondyle, the adductor tubercle and the gastrocnemius tubercle [1]. Viste et al. described recently the femoral insertion of the MPFL [19]. For them, the adductor tubercle is a reliable landmark to locate the femoral insertion of the MPFL which is 10 mm below. They advise to use the adductor tubercle for reconstructions of the MPFL. In our study, the femoral insertion of the MPFL was at a distance from the adductor tubercle: a mean 8.7 mm below and 3.6 mm in front of the adductor tubercle. The femoral insertion of the MCL was very close to the femoral insertion of the MPFL. In our study, the femoral insertion of the MPFL was located behind the femoral insertion of the MCL in 80% of the cases, on the femoral insertion of the MCL in 14% of cases and in front of the femoral insertion of the MCL in 6% of cases. Anatomical variations appear to exist concerning the femoral insertion of the MPFL.

The MPFL is an anisometric ligament because the length between the points of patellar and femoral insertion vary during flexion and extension of the knee. The distance between the point of insertion on the upper patellar and the femoral insertion of the MPFL increased during flexion and the distance between the insertion on the lower patella and the femoral insertion of the MPFL decreased during flexion (Figs. 8, 9). If the length between the patellar and femoral insertions changes and the MPFL is an inextensible structure, this suggests that there should be a direct relationship between the length changes and variations in tension of the MPFL during flexion.

If the distance between the point of insertion on the upper patella and the point of femoral insertion of the MPFL increases during flexion, this suggests that tension in the upper MPFL increases during flexion. On the other hand, if the distance between the point of insertion on the lower patella and the femoral insertion of the MPFL decreases during flexion, this suggests that the lower MPFL relaxes during flexion. These results are coherent with the anatomy of the knee, in particular with the double spiral shape of the femoral condyles [9]: the radius of the curve of the medial femoral condyle increases from front to back to point *t*, then decreases from this point *t* to behind femoral condyles (Fig. 13).

Inter-individual variations of the femoral insertion of the MPFL previously described affect the isometry of the MPFL. Thus, the position of the femoral insertion of the MPFL is necessarily a potential factor of patellofemoral instability.



a

Knee	IL (0°)	Angle 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	Range (mm)
1	52	0	0	0	-2	-2	-2	-2	-3	-4	-7	-7	-7	-7	-7	7
2	76	0	0	0	0	1	1	1	2	3	5	5	5	5	5	5
3	70	0	0	0	0	1	2	2	2	2	2	2	3	3	3	3
4	55	0	0	0	0	0	0	-1	-2	-3	-4	-7	-7	-8	-8	8
															Average of range :	5,75

b

Fig. 11 **a** Graph showing the difference "IL–IL(0°)" depending on the degree of flexion. The dotted gray curve shows the trend curve. **b** Table showing the "IL–IL(0°)" differences for each degree of flexion. During flexion, the mean change in length throughout knee flexion between insertion on the lower patella and the proximal the femoral insertion of the MCL was 5.75 mm

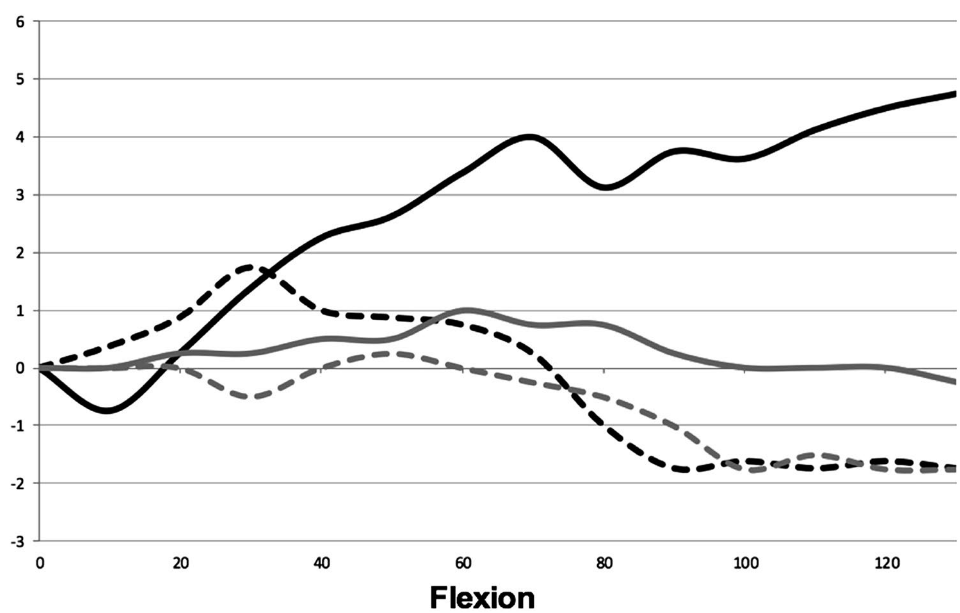


Fig. 12 Graph showing the four superimposed trend curves. The gray area between the two black curves is the interval of the variations in length between the patellar and femoral insertions of the native MPFL

In our study, there was less difference in the length between the point of patellar insertion of the MPFL and the posterior aspect of the femoral insertion of the MCL (which corresponds to the points of insertion during MPFL reconstruction according to the pediatric Chotel technique) than between the patellar and femoral insertions of the native MPFL (Fig. 12). Since the isometry of the graft is not the same as the native MPFL, this is a non-anatomical

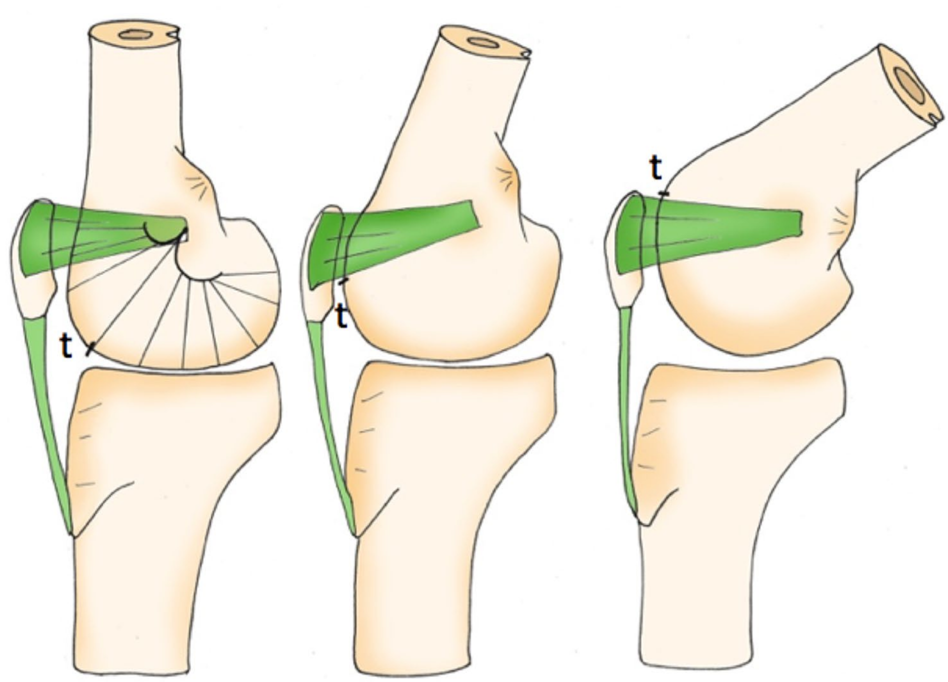


Fig. 13 Medial view of the right knee: the radius of the curve of the medial femoral condyle increases from front to back to point *t*, then decreases from this point *t* to behind the condyle

reconstruction. Thus, the reconstructed MPFL according to this pediatric technique is less anisometric than the native MPFL.

The patellar retinaculum is known to prevent lateral translation of the patella during knee flexion. Its resistance is 208 N [10]. The first studies by Amis et al. showed that the MPFL was the main restraint against lateral translation for the first 40° of flexion [2]. Philippot et al. reported that patellar stabilization was ensured by the MPFL at 30° of flexion [13]. After 40° of flexion, the patella is stabilized by the medial patellomeniscal and the medial patellotibial ligamentary complex associated with patellofemoral congruence [7, 13]. Thus, observations about length the insertions of the MPFL outwith the range relevant to MPFL function (after 40° of flexion) must be interpreted with cautions.

All these observations suggest several practical comments:

- Reconstruction of the MPFL by the pediatric technique is less anisometric, thus the tension on the patella from the graft is only slightly modified during flexion and extension.

- There is very little variation in graft tension during flexion and extension despite the variation in the radius of the curve of the femoral condyle. Thus, correct graft tension can provide both good passive patellofemoral stabilization and prevent pain or stiffness during flexion.

- By placing the knee at 30° of flexion, the patella is engaged in the femoral trochlea [14], and thus in the correct position. The graft can be stretched in this position with no risk of medializing the patella.

Although numerous morphological descriptions of the medial patellar retinaculum and the MPFL have been described in fresh cadaveric knees (15), the isometricity of the native and reconstructed MPFL was only evaluated in a small group (8 and 4 knees, respectively). The trends observed must be interpreted with caution. Furthermore, use a goniometer to define the knee flexion is not a precise method and the reliability of measurement with goniometer has not been assessed. This could lead to inaccuracies. Age of specimens (85 years) and the likely presence of age-related changes to ligaments and associated bone and soft tissues such as changes in elastic properties of tissues, osteoarthritis, disrupt results and constitute bias towards the generalization of observations, especially in children. Moreover, the ex vivo conditions are a limitation to this study. Patellofemoral stability is obtained by passive (medial patellar retinaculum, patellofemoral joint) as well as active stabilizers, in particular the quadriceps, whose role was not taken into consideration in this study. Contraction of the quadriceps during knee flexion mobilizes the patella and thus inevitably changes MPFL tension.

To deepen the knowledge about anatomical bases of the MPFL reconstruction, further works will need to be done. Performing surgical reconstruction in cadavers to compare measurements of the anatomical points, and perhaps to study contact pressures between patella and femur during knee flexion would allow the beginnings of extrapolating laboratory findings to surgical techniques in vivo.

Conclusion

The medial patellofemoral ligament (MPFL) seems to be a constant ligament, found on all studied knees. It is a major element of the medial patellar retinaculum, and its patellar insertion involves three-fourth of the upper medial border of the patella. Its femoral insertion is usually located immediately behind the femoral insertion of the medial collateral ligament (MCL). The distances between the patellar and femoral insertions vary during flexion: the MPFL is, therefore, an anisometric ligament.

Although we must remain cautious about the generalization of findings to children because this anatomical study was done on ex vivo old specimens, surgical reconstruction of the MPFL by the pediatric Chotel technique is an interesting option: the bone is preserved; there is no foreign material and the growth cartilage and perichondral ring remain intact.

Author contributions CD and LG contributed to study design, realized dissections, contributed to data analysis and draft of the manuscript. CS, AC and SP made critical revisions to the manuscript. AH supervised the study, contributed to analysis and interpretation of data and made critical revisions to the manuscript. All the authors read and approved the final manuscript prior to submission.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix 1

See Table 1.

Table 1 Summarizing observations and measurements of the descriptive study

No.	Age	Gender	Femoral insertion of the MPFL in relation to the proximal insertion of the MCL	Patellar insertion of the MPFL			Length (mm) upper border MPFL	Distance (mm) MPFL/adductor tubercle	
				Size (mm) Medial part of the patella	Size (mm) Patellar insertion	Ratio		Below	In front of
1	86	M	In front	45	35	0.78	65	10	4
2	90	M	Behind	50	30	0.60	65	5	5
3	64	M	Behind	50	30	0.60	70	20	10
4	73	F	Behind	37	30	0.81	60	1	0
5	78	M	On	45	35	0.78	65	25	15
6	85	M	Behind	40	35	0.88	75	5	5
7	100	F	Behind	40	30	0.75	62	15	5
8	71	F	Behind	50	50	1.00	72	10	0
9	93	F	Behind	35	15	0.43	60	5	0
10	96	M	Behind	50	30	0.60	59	5	0
11	84	M	Behind	45	30	0.67	59	10	0
12	90	F	Behind	45	27	0.60	59	3	0
13	89	F	Behind	50	45	0.90	73	3	5
14	86	M	Behind	55	35	0.64	68	3	5
15	94	F	On	50	35	0.70	55	10	0
Mean	85.3	M: 8/15		45.8	32.8	0.71	64.5	8.7	3.6

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