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The extensor mechanism of the knee joint: an anatomical study

Received: 15 February 2005
Accepted: 2 April 2005
Published online: 10 November 2005
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Abstract This study investigated the anatomy of the structures that form the extensor mechanism of the knee joint using microsurgical techniques. Ten fresh-frozen human adult cadaveric knees were used. The quadriceps components, the infra-patellar tendon, the patellofemoral ligaments, and their relations to the neighboring anatomical structures were measured. The angles of the vastus lateralis and the vastus medialis muscle fibers to the rectus tendon were 26.6 and 41.1°, respectively. The medial patellofemoral ligament connecting the femoral medial epicondyle to the medial edge of the patella was approximately 54.2 mm long, and its width ranged from 9 to 30 mm. The medial patellomeniscal ligament had a wide attachment to the meniscus whereas the attachment to the patella was

narrow. The patellar tendon was 31.9 mm broad at its attachment to the apex of the patella and 27.4 mm wide at its attachment to the tibial tubercle. It was 38–49 mm long. Using the surgical microscope we were able to dissect and identify a trilaminar arrangement of prepatellar fibrous soft tissues. Also, we were able to identify the vessels and nerves around the patella. Details of clinical relevance and the possible pathological implications of the material presented are discussed. Emphasis is placed on the stability of the patellofemoral joint and the complex interaction between a range of factors providing it.

Keywords Extensor mechanism · Quadriceps tendon · Vastus medialis · Medial patellofemoral ligament · Patellofemoral instability

Introduction

The extensor mechanism of the knee joint has received a great deal of academic and clinical attention. It consists of a complex arrangement of various muscles, tendons, ligaments, and soft-tissue structures. These structures include the quadriceps muscle and its common tendon, the patellar tendon, the retinaculum, the pre-patellar structures, the Hoffa's fat pad, and the quadriceps pouch.

Knowledge of the anatomy of the extensor mechanism is essential for an understanding of patellofemoral stability. The stability of the patellofemoral joint is

provided by both dynamic and static stabilizers, in addition to the bony architecture [15]. Passive laxity of the patella is prevented by the peripatellar retinaculum. Medially, the restraints include a capsular condensation in addition to the patellofemoral and patellotibial ligaments [14]. Thus, the patellar tendon is a primary restraint in the coronal plane and limits patellar excursion to 10 mm proximally [11]. The "balance" of the static restraints is maintained by the dynamic restraints [26]. These are mainly the quadriceps muscle with its four components and secondarily the iliotibial band [16].

Various studies have described the possible role of anatomic variations in the quadriceps mechanism in relation to abnormal conditions [4, 9, 26]. Subluxation of the patella has been associated with multiple anatomic findings, including dystrophy of the vastus medialis (VM) muscle, external tibial torsion, lateral insertion of the patellar tendon, genu valgum, and patella alta [17].

Based on the deductions of two previous studies, in which we used microsurgical techniques [7, 21], we assumed that a microanatomical dissection of this region could answer some of the questions about the complex anatomy of the extensor mechanism.

Materials and methods

Ten fresh-frozen human adult cadaveric knees were used for the study. They were maintained at -20°C and prior to the dissection were thawed at room temperature for 18 h. There were six right and four left knees, seven male and three female, with a mean age of 55 years. There was no evidence of marked bony abnormality or degenerative disease. Ligamentous integrity was also ensured. All specimens included at least 12 cm of bone and soft tissue on each side of the knee joint.

The dissections were begun by first separating the skin and subcutaneous tissue over the anterior aspect of the knee from the superficial fascia. The dissection was then extended laterally and medially. Once the patella had been reached, each layer was sequentially incised longitudinally in the midsagittal plane. The dissection of each layer was then extended proximally, distally, medially, and laterally. When a separate aponeurotic layer was identified deep in the superficial transverse fascia, it was incised longitudinally. The separation of the layer was extended proximally, distally, medially, and laterally. The presence and character of the remaining soft tissues anterior to the patella, such as the continuation of the rectus femoris fibers, were also documented.

The procedure was performed using magnifying loupes (magnification 3.5 \times). After the trilaminar

arrangement of prepatellar fibrous soft tissues, we continued the dissection proximally to identify the four main muscular elements of the quadriceps. We measured the superficial length of the quadriceps tendon from the patellar base to the myotendinous junction of the rectus femoris (Table 1). We also measured its width at the superior aspect of the patella as well as at its half-length with the millimetric scale of a ruler. The rectus femoris and vasti were dissected apart and reflected distally while the details of their tendinous insertions were noted carefully.

A careful dissection of all ligamentous structures of the anterior aspect of the knee joint was then performed using an operative microscope (magnification 6 \times and 10 \times) and microsurgical instruments (microsurgical scissors and forceps).

Dissecting the area, care was taken to identify the vascular anastomosis and nerves around the patella.

All the anatomic components were photographed and dimensions were recorded using a micrometer. The anatomical variations, ligament shapes, separated bundles of the ligaments, and topography of ligament attachments were also described and recorded.

Results

The extensor mechanism consisted of four distinct muscle bellies (quadriceps muscle) that shared a common tendon of insertion (Fig. 1). The quadriceps tendon was trilaminar, with the anterior layer formed by the rectus femoris, the intermediate layer formed by the VM and vastus lateralis (VL), and the deep layer by the tendon of the vastus intermedius (Fig. 1).

The rectus femoris narrowed to a tendon which inserted into the superior pole of the patella. With the knee flexed the mean distance of the most superficial layer of the quadriceps tendon from the anterosuperior part of the patella to the myofascial junction of the rectus femoris was 68 mm (SD 11.01) (Fig. 1).

The VL extended halfway down, giving off a fibrous expansion. It blended with the lateral patellar retinacu-

Table 1 Dimensions (in mm) of the anatomical structures of the extensor mechanism of the knee

		Range (mm)	Average (mm)	SD
Quadriceps tendon	Length	50–85	68.00	11.01
	Width (at the superior aspect of the patella)	33–55	41.10	7.00
	Width (in the middle)	14–28	22.70	4.16
Angle between RF tendon and VM and VL ($^{\circ}$)	VM	30–57	45.50	8.40
	VL	20–38	26.60	6.19
Patellar tendon	Length	38–49	43.00	3.74
	Width (at the margin of the patella)	27–38	31.90	3.60
	Width (tuberosity of the tibia)	24–35	27.40	3.57
MPFL	Length	46–64	54.20	6.09
	Width	9–30	207.00	6.04

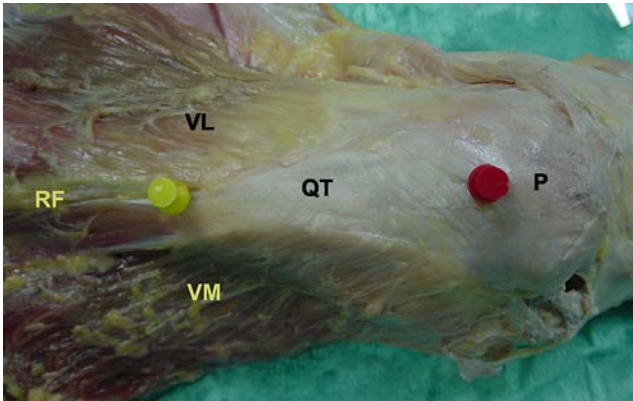


Fig. 1 The quadriceps tendon (*QT*) is trilaminar, with the anterior layer formed by the rectus femoris (*RF*), the intermediate layer formed by the vastus medialis (*VM*) and vastus lateralis (*VL*) and the deep layer (*not visible*) by the tendon of the vastus intermedius and patella (*P*). The pins are sited at the proximal and distal ends of the superficial quadriceps tendon

lum, through which there was a direct attachment to the tibia.

The *VM* was a muscle which formed the intermediate layer having the most distal fibers passing almost horizontally and anteriorly toward their insertion into the common tendon and the medial border of the patella. This part of the muscle was sometimes described as the vastus medialis obliquus (*VMO*) (Fig. 2). Like the *VL*, the *VM* had a distal fibrous expansion that blended with the medial patellar retinaculum.

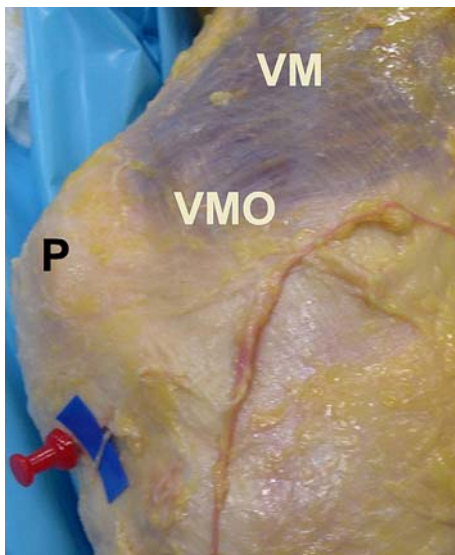


Fig. 2 The vastus medialis (*VM*) has a distal fibrous expansion that blends with the medial patellar retinaculum. The most distal fibers of the *VM* are almost horizontal as they pass anteriorly to the insertion into the common tendon and the medial border of the patella (*P*). This part of the muscle is sometimes described as the vastus medialis obliquus (*VMO*)

The vastus intermedius partly blended with the *VM* medially. The fibers of the rectus femoris and vastus intermedius inserted almost perpendicularly into the superior pole of the patella, whereas the fibers of the *VM* and *VL* inserted obliquely.

A goniometer was used to measure the angles of the muscle fibers to the rectus tendon, which was 26.6° (SD 6.18) for the *VL* and 45.5° (SD 8.39) for the medialis (Table 1).

The width of the quadriceps tendon at mid-length and at the superior aspect of the patella was 22.7 mm (SD 4.16) and 41.1 mm (SD 6.99), respectively (Table 1). The common tendon inserted into the patella.

Medial and lateral portions of the quadriceps tendon passed down on either side of the patella and inserted into the proximal tibia on either side of the tuberosity. These expansions merged into the capsule, forming the medial and lateral retinacula.

On the medial side of the knee a band of retinacular tissue connected the femoral medial epicondyle to the proximal two-thirds of the medial edge of the patella forming the medial patellofemoral ligament (*MPFL*) (Fig. 3). The *MPFL* was approximately 54.2 mm (SD 6.08) long, and its width ranged from 9 to 30 mm (Table 1). It was overlaid by the distal part of *VMO* to a variable extent, and fibers of *MPFL* merged into the deep aspect of the muscle (Figs. 4, 5).

From the inferior border of the medial patellar edge the medial patellomeniscal ligament (*MPML*) connected the patella to the anterior horn of the medial meniscus (Fig. 6). The *MPML* had a wide attachment to the meniscus where the fibers fanned out making it difficult to define the posterior margin of the ligament.

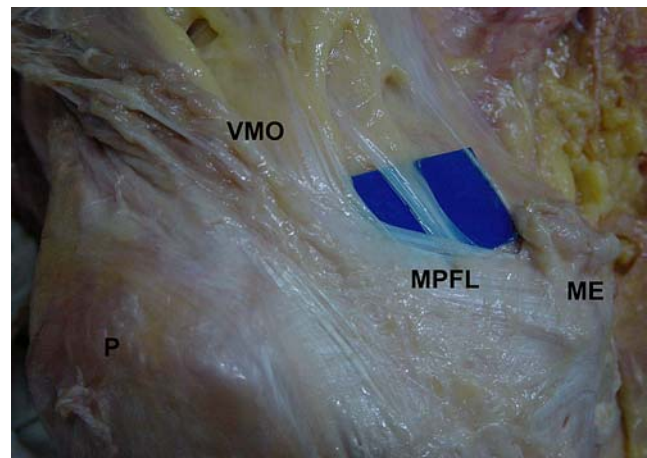


Fig. 3 On the medial side of the knee the medial patellofemoral ligament (*MPFL*) consists of a band of retinacular tissue which connects the femoral medial epicondyle (*ME*) to the proximal two-thirds of the medial edge of the patella (*P*) and vastus medialis obliquus (*VMO*)

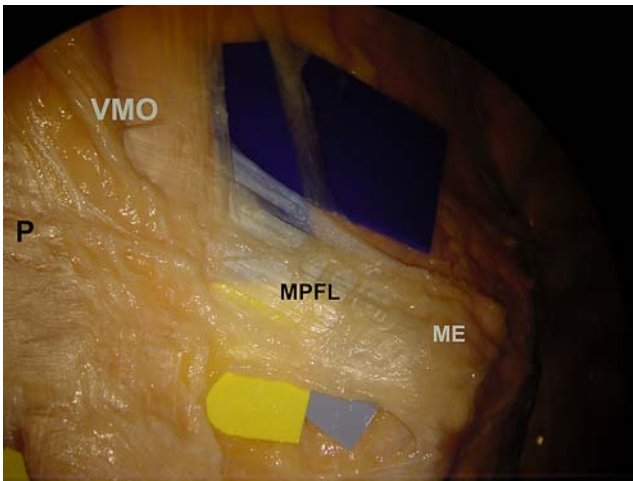


Fig. 4 The medial patellofemoral ligament (*MPFL*) is overlaid by the distal part of the vastus medialis obliquus (*VMO*) to a variable extent, and fibers of *MPFL* merged into the deep aspect of the muscle; medial epicondyle (*ME*) and patella (*P*)

On the lateral side of the knees, we identified the superficial oblique retinaculum. Posteriorly, the deep transverse retinaculum was found to consist of three major components: the transverse patellofemoral ligament or epicondylopatellar band, which coursed superolaterally, the transverse retinaculum, which coursed directly from the ITB to the midpatella and the patell-

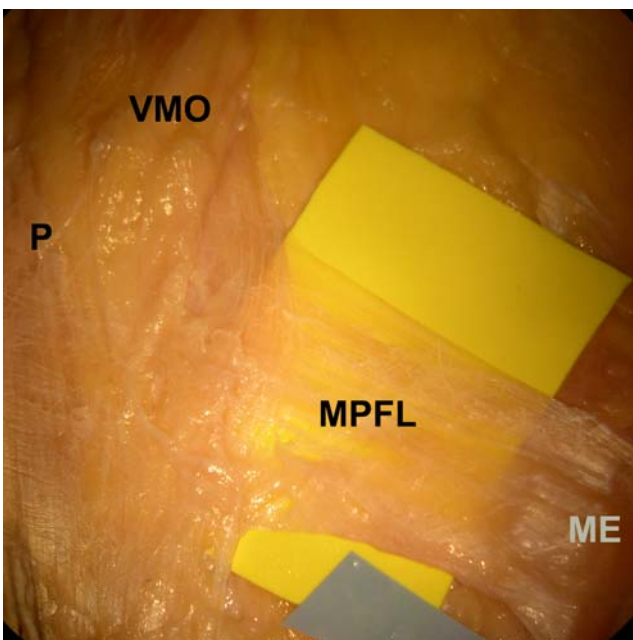


Fig. 5 The medial patellofemoral ligament (*MPFL*) is overlaid by the distal part of the vastus medialis obliquus (*VMO*) to a variable extent, and fibers of *MPFL* merged into the deep aspect of the muscle; medial epicondyle (*ME*) and patella (*P*)

otibial band, which ran between the patella and the tibia inferiorly.

A trilaminar arrangement of prepatellar fibrous soft tissues was observed in all knees dissected, similar to the findings of Dye et al. [8] (Fig. 7). All knees demonstrated a superficial fascial layer with orientation of the fibers transverse to the long axis of the patella (Fig. 8). One knee did not demonstrate an intermediate oblique aponeurotic layer. The fibers of this layer in the other knees had a more oblique orientation and were contributed to by expansions of the VL and VM tendons as well as the more superficial fibers of the rectus femoris. An incision of this intermediate aponeurotic layer revealed the deep longitudinally oriented fibers of the rectus femoris anterior to the patella (Fig. 9). All knees had a continuation of the rectus femoris fibers, which were always inserted directly into the anterior patellar bone.

The patellar tendon was a flat structure derived primarily from the central fibers of the rectus femoris that extended distally over the anterior surface of the patella. It inserted on the tibial tubercle, usually beginning just distal to the tubercle's most superior extreme. It continued past the tubercle to blend with the fascial expansions of the iliotibial tract on the anterior surface of the tibia. It was 31.9 mm (SD 3.6) broad at its insertion into the apex of the patella and 27.4 mm (SD 3.5) wide at its insertion into the tibial tubercle. It was 38–49 mm long (Table 1).

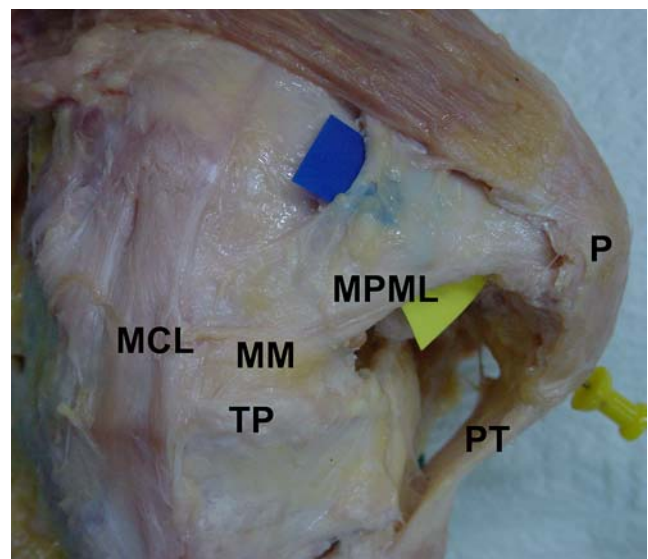


Fig. 6 The medial patellomeniscal ligament (*MPML*) connects the inferior border of the medial patellar edge (*P*) and the anterior horn of the medial meniscus (*MM*). The *MPML* had a wide attachment to the meniscus where the fibers fanned out making it difficult to define the posterior margin of the ligament; medial epicondyle (*ME*); medial collateral ligament (*MCL*); tibial plateau (*TP*), and patella tendon (*PT*)

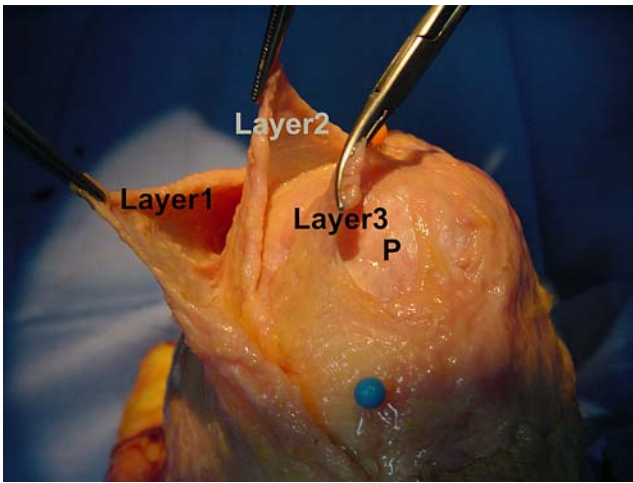


Fig. 7 The trilaminar arrangement of prepatellar fibrous soft tissues. The superficial fascial layer (layer 1) with orientation of the fibers transverse to the long axis of the patella, the intermediate oblique aponeurotic layer (layer 2) and the deep longitudinally oriented fibers of the rectus femoris anterior to the patella (layer 3)

The infrapatellar fat pad covered the extra-articular portion of the posterior patellar surface. The fat pad extended superiorly to merge with the peripatellar fold on both sides of the patella. It was pierced by numerous blood vessels derived from the genicular arteries.

Dissecting the anterior aspect of the knee, care was taken to identify the infrapatellar branch of the saphenous

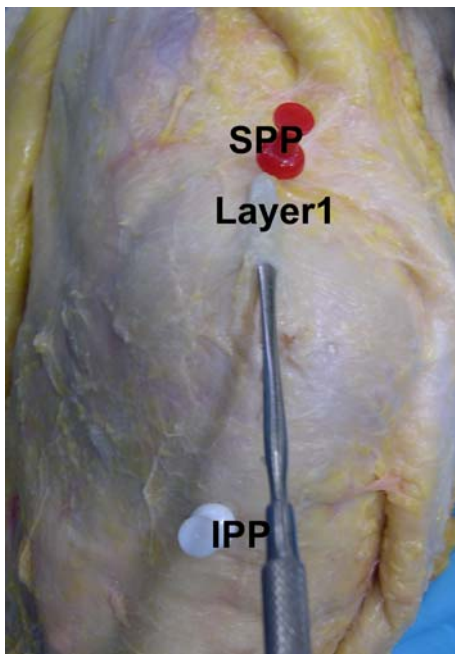


Fig. 8 The fibers of the superficial fascial layer (layer 1) have an orientation transverse to the long axis of the patella; superior pole of the patella (SPP); inferior pole of the patella (IPP)

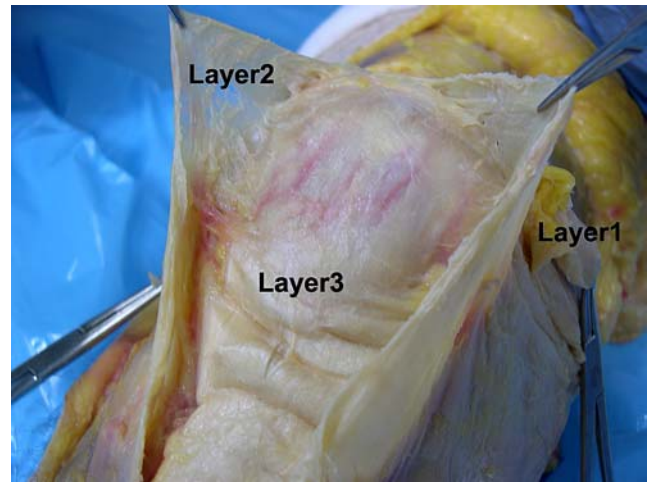


Fig. 9 The fibers of the intermediate layer (layer 2) have a more oblique orientation and were contributed to by the expansions of the vastus lateralis and vastus medialis tendons as well as the more superficial fibers of the rectus femoris. An incision of this intermediate aponeurotic layer revealed the deep longitudinally oriented fibers of the rectus femoris anterior and adherent to the patella (layer 3); retracted superficial fascial layer (layer 1)

nous nerve (Fig. 10). It traversed the sartorius muscle and joined the patellar plexus, providing innervation to the anteromedial capsule, patellar tendon, and skin anteromedially.

A vascular circle was identified around the patella, which according to Scapinelli [29], supplied the patella by nutrient arteries that entered predominantly at the inferior pole.

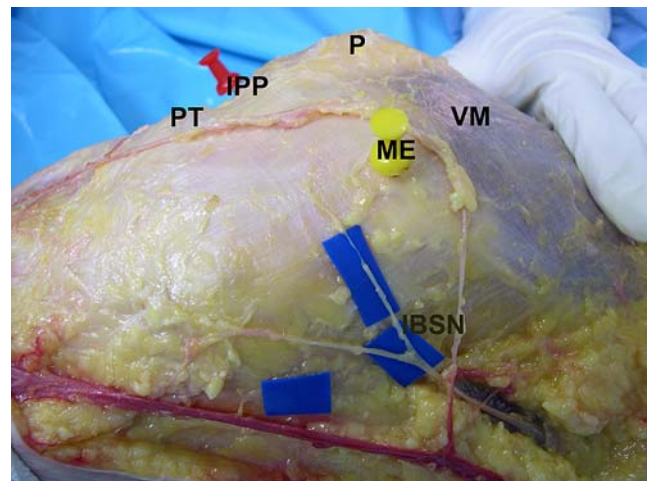


Fig. 10 The infrapatellar branch of the saphenous nerve (IBSN) traversed the sartorius muscle and joined the patellar plexus, providing innervation to the anteromedial capsule, patellar tendon (PT), and skin anteromedially; patella (P), inferior pole of the patella (IPP), vastus medialis (VM), and medial epicondyle (ME)

Discussion

An accurate and ever-improving knowledge of musculoskeletal structure and the associated relationships should be a fundamental goal for all orthopedic surgeons. For those with an interest in the knee joint, the anatomy and biomechanics of the extensor apparatus present a substantial challenge [19].

Despite the prevalence of literature describing the morphology and function of the VMO as an individual muscle, limited bibliography actually substantiates the existence of the VMO as a separate, distinct muscle from the vastus medialis longus (VML) [14].

The VMO muscle is reported to be the primary stabilizer of the patella during knee extension. Many articles have been published describing the fiber alignment, nerve innervation, function, sequela from injury to and/or atrophy of the VMO and its rehabilitation [1, 4, 9, 15, 20, 26]. However, it remains controversial if the VMO appears to be an anatomically and functionally separate structure from the VML [14]. The average fiber angle measurements seen in this study of 45.5° for the distal fibers of the VM are in agreement with previously published VM fiber angle measurements. Koskinen and Kujala, however, have noted more proximal insertion of the VM in patients with patellar dislocation [18]. Understanding the relationship between the VMO morphology and patellar tracking [19] will be useful in diagnosis, treatment, and prevention of patellar subluxation and dislocation.

The MPFL, although varying in thickness and quality [2, 10, 31], was found to be the major medial soft-tissue restraint to patellar lateral displacement [2, 5, 13]. Its stabilizing role in the normal knee and its injury as an essential lesion of patellar instability has been appreciated only recently [2, 31]. There is a 97% incidence of traumatic tears of the MPFL in acute patellar dislocation. Lateral patellar displacement tests in vitro showed that the patella subluxed most easily at 20° knee flexion [9, 28]. Isolated release resulted in a 50% increase in lateral displacement. We found, in agreement with Tuxoe et al. [38], that the distal edge of the MPFL was very often difficult to define. Therefore, we may find difficulties in surgical exploration of this ligament.

In addition, the patellotibial and patellomeniscal ligament complex have been found to play an impor-

tant secondary role in restraining lateral patellar displacement. Isolated repair of these ligaments restored balance to near normal levels [13]. In our study, similar to the findings of Feller et al. [10] and Tuxoe et al. [38], we found that the patellar insertion of the PML is very narrow and the meniscal insertion very wide. This could explain why many patients with acute lateral patellar dislocation have a tear from the inferior medial part of the patella at the attachment of the PML. Management should, therefore, be directed both at correcting anatomic abnormalities when indicated, and at reconstruction of medial restraints of patellar tracking [3, 9, 11].

The arterial supply of the human patellar ligament has been systematized on 20 knees by Soldado et al. [32]. We observed three arterial pedicles: superior, middle, and inferior placed on each side of the patellar ligament. Medial pedicles had their origin from the descending and the inferior medial genicular arteries. The lateral pedicles took their origin from the lateral genicular arteries and the recurrent tibial anterior artery. Two main vascular arches anastomosed with these pedicles: the retropatellar and the supratubercular.

A goal of this study was to define carefully the anatomic distribution of the infrapatellar branch of the saphenous nerve. Tifford et al. [37] with an anatomic study provide the surgeon with reliable parameters as to where the nerve is most commonly encountered and specific surgical recommendations to minimize the risk of nerve injury.

In conclusion, the findings of this study should help in understanding the complex function of the extensor mechanism, which demands knowledge of not only its anatomic structures but of their balanced relationships as well. An awareness of a layer concept of tissue orientation is helpful in understanding surgical access as well as the normal function of the decelerator mechanism. This awareness is a prerequisite to the evaluation and treatment of musculoskeletal disorders [36].

Such a disorder is the recurrent dislocation or subluxation of the patellofemoral joint, which is always a challenge to the orthopedic surgeon. Once a correct diagnosis is established, appropriate treatment plans, including both non-operative and operative methods, may yield consistent results.

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