The anatomy of the posterolateral aspect of the rabbit knee

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Abstract

The purpose of this study was to determine the anatomy of the posterolateral aspect of the rabbit knee to serve as a basis for future in vitro and in vivo posterolateral knee biomechanical and injury studies. Twelve nonpaired fresh-frozen New Zealand white rabbit knees were dissected to determine the anatomy of the posterolateral corner.

The following main structures were consistently identified in the rabbit posterolateral knee: the gastrocnemius muscles, biceps femoris muscle, popliteus muscle and tendon, fibular collateral ligament, posterior capsule, ligament of Wrisberg, and posterior meniscotibial ligament. The fibular collateral ligament was within the joint capsule and attached to the femur at the lateral epicondyle and to the fibula at the midportion of the fibular head. The popliteus muscle attached to the medial edge of the posterior tibia and ascended proximally to give rise to the popliteus tendon, which inserted on the proximal aspect of the popliteal sulcus just anterior to the fibular collateral ligament. The biceps femoris had no attachment to the fibula and attached to the anterior compartment fascia of the leg.

This study increased our understanding of these structures and their relationships to comparative anatomy in the human knee. This knowledge of the rabbit's posterolateral knee anatomy is important to understand for biomechanical and surgical studies which utilize the rabbit knee as a model for human posterolateral knee injuries.
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Keywords: Knee anatomy; Fibular collateral ligament; Popliteus; Posterolateral corner

Introduction

In efforts to perform in vivo studies on the natural history of posterolateral knee injuries and in comparing the results of surgical procedures in rabbit knees to in vitro human biomechanical studies [13], we found a paucity of information on the anatomy and function of the posterolateral aspect of the rabbit knee. While there is information in the literature on the evolution and comparative anatomy of the knee joint of different species, most of these articles deal with general features and were not detailed enough to allow a proper assessment of their specific anatomic components [6,7]. We were unable to find any articles in either the human or veterinary literature which provided details of the anatomy or function of the rabbit posterolateral knee structures. With this in mind, the purpose of this study was to perform a detailed analysis of the anatomy of the posterolateral aspect of the rabbit knee, similar to previous studies of the human knee [21,22]. We believe that this study may prove useful for future in vitro biomechanical studies and for in vivo studies which utilize the rabbit knee as a posterolateral knee injury model.

Materials and methods

Approval was obtained for this study from the Institutional Animal Care and Use Committee. Twelve nonpaired fresh-frozen adult New Zealand white rabbit knees were dissected for an anatomic study of the posterolateral knee. The hind limb of the rabbit was disarticulated at the hip joint and the skin removed. The individual muscles of the leg and thigh were separated along fascial planes and the posterolateral structures exposed by cutting the calcaneal (achilles) tendon and reflecting the gastrocnemius and flexor digitorum superficialis (FDS) muscles. The medial and lateral gastrocnemius muscle bellies were identified, as well as the popliteus muscle complex, the fibular collateral ligament, and the posterolateral joint capsule. Cutting through the posterior capsule exposed the ligament of Wrisberg, and other intra-articular structures. The specimens were photographed and the anatomic components identified. Measurements of these structures and their relationships to specific anatomic landmarks were also performed. The range and standard deviation (SD) of the measurements were also calculated.

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Results

Overview of bony anatomy

The rabbit knee joint consisted of tibiofemoral and patellofemoral articulations. The femur had well-developed condyles and a deep intercondylar notch. The trochlear groove was a well-defined structure with a prominent lateral ridge. The trochlear groove was deep and long, extending proximally on the femoral shaft an average of 17.2 mm (range: 15.7–18.5 mm, SD: 0.89 mm). The lateral tibial plateau was convex and sloped laterally and posteriorly (Fig. 1). The tip of the fibular styloid was 9.5 mm (range: 8.1–10.2 mm, SD: 0.64 mm) distal to the edge of the lateral tibial plateau at this location. At the fibular head and styloid, a bony syndesmosis was present which allowed for no motion of the proximal tibiofibular joint. Just distal to the styloid, a separate fibula and tibia were identified. Moving distally an average of 42.1 mm (range: 37.3–48.8 mm, SD: 3.51 mm) from the midportion of the lateral aspect of the distal articular cartilage margin of the lateral tibial plateau, the tibia and fibula fused again to form one tibiofibula, which averaged another 55.1 mm (range: 49.6–63.0 mm, SD: 4.76 mm) in length distally to the ankle joint.
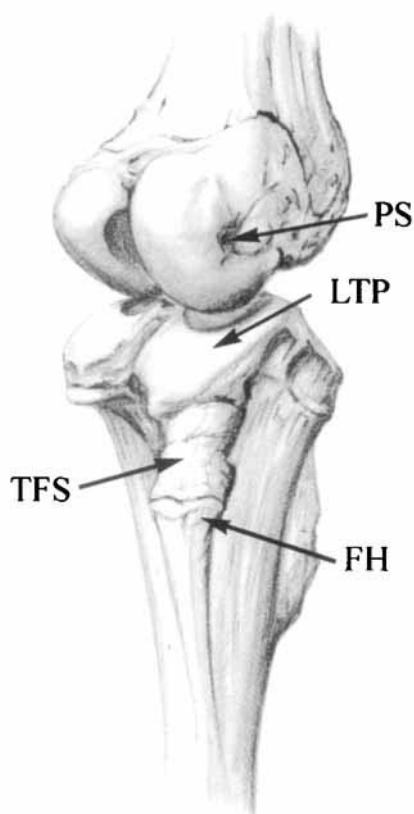

Fig. 1. Bony anatomy of the rabbit knee showing the slope of the lateral tibial plateau (LTP), fibular head (FH), tibiofibular syndesmosis (TFS), and popliteal sulcus (PS).

Anatomy of individual structures

Table 1 lists the measurements of individual anatomic structures. Table 2 reports on the relationships of some selected anatomic structures to specific bony landmarks or attachment locations.

Popliteus muscle and tendon

The rabbit popliteus muscle was a large muscle with a muscular attachment along the posteromedial edge of the tibia. This attachment began immediately distal to the medial tibial plateau and extended distally along the tibia an average of 30.0 mm (range: 22.6–49.5 mm, SD: 7.61 mm). A thin posterior aponeurotic expansion covered the popliteus tendon and part of the muscle near its musculotendinous junction. This fascia had no bony attachments. Removing this aponeurotic fascial expansion exposed the popliteus tendon (Fig. 2). The popliteus tendon was a strap-like tendon averaging 9.3 mm (range: 7.6–10.9 mm, SD: 1.0 mm) long and 3.1 mm (range: 2.5–3.7 mm, SD: 0.36 mm) wide. With the knee

Table 1
Measurements of anatomical structures of the rabbit knee

Structure	Mean (mm) (12 knees)	SD (mm)	Range (mm)
Tibia			
Length	97.2	7.75	88.6–108.3
Femur			
Length	92.3	5.94	84.6–100.8
Medial sesamoid			
Diameter	3.7	0.47	2.9–4.6
Lateral sesamoid			
Length	8.7	0.57	7.7–9.5
Width	3.6	0.35	3.2–4.2
Popliteus tendon			
Length	9.3	1.0	7.6–10.9
Width	3.1	0.36	2.5–3.7
Medial tibial attachment of poplitcus muscle			
Length	30.0	7.60	22.6–49.5
Popliteal sesamoid			
Length	4.1	0.36	3.6–4.6
Width	3.4	0.31	3.0–3.8
Fibular collateral ligament			
Length	18.2	1.11	16.6–20.6
Width	2.5	0.23	2.2–2.9
Ligament of Wrisberg			
Length	7.5	0.53	6.9–8.5
Width	2.2	0.50	1.3–2.8
Posterior meniscotibial ligament			
Length	7.2	0.77	5.6–8.5
Width	2.3	0.52	1.3–3.0
Trochlear groove			
Length	17.2	0.89	15.7–18.5

Table 2
Mesurements of relationships between anatomical structures

| Relationship	Mean distance (mm) (12 knees)	SD (mm)	Range (mm)
Lateral tibial plateau[a] to proximal tibiofibular syndemosis	9.5	0.64	8.1–10.2
Lateral tibial plateau[a] to distal tibiofibular syndesmosis	42.1	3.51	37.3–48.8
Popliteus insertion on femur to FCL insertion on femur	3.4	0.62	2.5–4.6
FCL insertion on femur to lateral femoral condyle articular surface	4.6	0.69	3.8–5.7

[a] Measurements from the midportion of the lateral aspect of the lateral tibial plateau, distal articular cartilage margin.
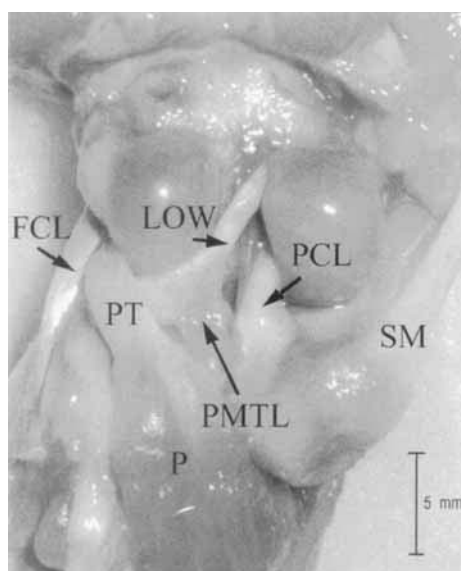
Fig. 2. Posterior view showing intraarticular and intracapsular structures: popliteus muscle (P), popliteus tendon (PT), fibular collateral ligament (FCL), ligament of Wrisberg (LOW), posterior meniscotibial ligament (PMTL), posterior cruciate ligament (PCL), and semimembranosus tendon (SM).
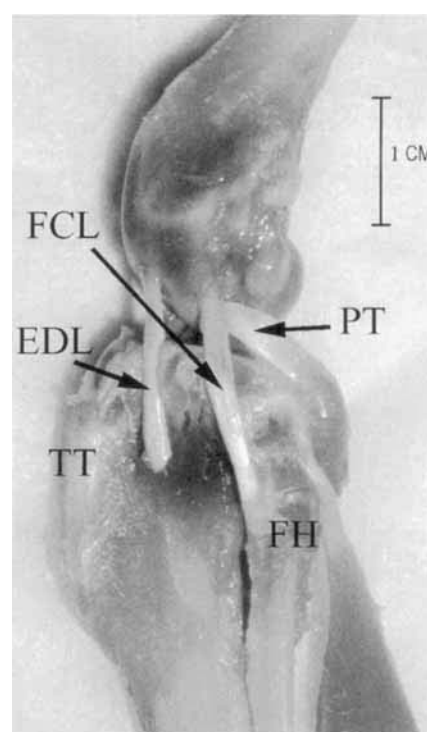

Fig. 3. Lateral view of the knee joint showing the tibial tubercle (TT), fibular head (FH), fibular collateral ligament (FCL), popliteus tendon (PT) and the tendon of the extensor digitorum longus (EDL).

near full extension, the tendon coursed at a 52.5° angle (range: 50–55°, SD: 2.7°) from the coronal plane of the tibia and became intraarticular at the lateral joint line. There were no distinct popliteal attachments to the lateral meniscus at the popliteal hiatus. The proximal portion of the popliteus tendon passed medial to the fibular collateral ligament and inserted at the proximal aspect of the popliteus sulcus on the lateral aspect of the femur, just distal and slightly anterior to the attachment of the FCL on the lateral epicondyle (Fig. 3).

In all cases a sesamoid bone, commonly referred to as the cyamella, was found at the musculotendinous junction of the popliteus. The cyamella was anterior to the popliteus tendon and was elliptical in shape, averaging 4.1 mm (range: 3.6–4.6 mm, SD: 0.36 mm) long and 3.4 mm (range: 3.0–3.8 mm, SD: 0.31 mm) wide. It articulated with the posterolateral aspect of the lateral tibial plateau. The posterior joint capsule of the proximal

tibiofibular joint capsule coursed between the posteromedial aspect of the fibula to the musculotendinous junction of the popliteus and the cyamella. This posterior capsule was very thin and no distinct popliteofibular ligament (PFL) was identified.

Fibular collateral ligament

The fibular collateral ligament was a stout ligament averaging 18.2 mm (range: 16.6–20.6 mm, SD: 1.11 mm) long and 2.5 mm (range: 2.2–2.9 mm, SD: 0.23 mm) wide. Proximally, it attached to the lateral femoral epicondyle, just proximal and slightly posterior to the insertion of the popliteus tendon on the femur. It was
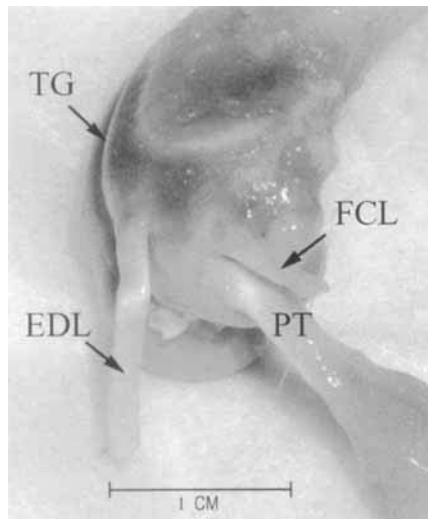
Fig. 4. View of the lateral femoral condyle showing the trochlear groove (TG), and the relationship of the fibular collateral ligament (FCL) and the popliteus tendon (PT). The extensor digitorum longus (EDL) tendon is also noted.

enveloped within the lateral joint capsule and attached distally on the midportion of the lateral aspect of the fibular head (Fig. 4).

Biceps femoris muscle

The biceps femoris muscle was a large and broad muscle comprising most of the lateral thigh musculature. At the knee, it had a large fascial expansion that extended from the lateral aspect of the patella distally down the leg. This fascial expansion was superficial and covered the anterior compartment of the leg. No distinct tendinous attachments were present distally as the fascial expansion attached to the anterior compartment fascia of the leg and the lateral aspect of the lateral gastrocnemius musculature. In addition, there were no attachments of the biceps femoris to the fibula.

Medial head of the gastrocnemius

After removing the skin of the posterior knee and leg, the large gastrocnemius muscles were seen. The medial head of gastrocnemius had a tendinous attachment to the posteromedial aspect of the distal femur, just proximal to the medial femoral condyle. Moving laterally on the posteromedial femur, this attachment became muscular. Just distal to the femoral attachment of the medial head of the gastrocnemius, there was a small round sesamoid bone, averaging 3.7 mm (range: 2.9–4.6 mm, SD: 0.47 mm) in diameter, which articulated with the posterior aspect of the medial femoral condyle. We will refer to this bone as the medial fabella. The medial head of the gastrocnemius attached to the posterior surface of the medial fabella, completely surrounding all but its articular surface.

Lateral head of the gastrocnemius

The lateral head of the gastrocnemius muscle had more complex attachments at the knee than the medial head of the gastrocnemius. Laterally, a fascial expansion from the muscle blended with the lateral fascia of the biceps femoris muscle. More medially, the muscle attached to the posterior surface of a large sesamoid bone, the lateral fabella. This peanut shaped lateral sesamoid bone averaged 8.7 mm (range: 7.7–9.5 mm, SD: 0.57 mm) long and 3.6 mm (range: 3.2–4.2 mm, SD: 0.35 mm) wide, and was larger than the medial fabella in all cases. The lateral gastrocnemius enveloped the majority of the lateral fabella and was unable to be separated from the posterior capsule proximal to the fabella. The third attachment of the lateral gastrocnemius was a tendinous attachment to the posterolateral aspect of the distal femur, just proximal to the lateral femoral condyle. This attachment on the distal femur became muscular at its more medial attachment.

Flexor digitorum superficialis

Anteromedial to the lateral gastrocnemius muscle was the FDS. The FDS had a proximomedial attachment to the lateral fabella. The FDS was anteromedial to the lateral gastrocnemius muscle as it coursed distally. Distally on the leg, the tendons from the gastrocnemius muscles and FDS made up the common calcaneal (achilles) tendon.

Posterior capsule

Reflecting the gastrocnemius muscles and FDS revealed the posterior capsule. The posterior capsule was noted to consist of both meniscofemoral and meniscotibial portions. Proximally, the meniscofemoral portion of the posterior capsule attached to the posterior aspect of the femoral condyles. Slightly distal to its femoral attachment, the capsule attached to the medial and lateral fabellae of the gastrocnemius muscles, completely enveloping their sesamoid bones except for their intraarticular articulations. Along this course, the medial and lateral gastrocnemius tendons were indistinguishable from the posterior capsule between its femoral and fabellar attachments. The posterior capsule then attached to the posterior horns of the medial and lateral menisci. Distally, the meniscotibial portion of the posterior capsule coursed from its meniscal attachments to attach to the proximal edge of the popliteus muscle and the posterior aspect of the tibia.

Posterior semimembranosus complex

The main attachment of the semimembranosus tendon was on a prominent tubercle on the posteromedial aspect of the proximal tibia. There was a distolateral, almost horizontal, fascial expansion of the semimembranosus, with some fibers blending with the posterior

capsule, which coursed to the medial border of the lateral sesamoid and the FDS.

Ligament of Wrisberg (posterior meniscofemoral ligament)

The ligament of Wrisberg attached to the posteromedial aspect of the intercondylar notch, posterior to the posterior cruciate ligament attachment, and extended distolaterally to the proximal border of the posteromedial corner of the posterior horn of the lateral meniscus. The ligament averaged 7.5 mm (range: 6.9–8.5 mm, SD: 0.53 mm) long and 2.2 mm (range: 1.3–2.8 mm, SD: 0.50 mm) wide at its midpoint. Upon extension of the knee, the ligament of Wrisberg was noted to pull the lateral meniscus proximally and posteriorly.

Posterior meniscotibial ligament

Separate from the meniscotibial portion of the posterolateral joint capsule, a separate ligament was present. It attached to the distal border of the posteromedial corner of the posterior horn of the lateral meniscus and ran distomedially in an oblique orientation to insert on the posterior tibia immediately lateral to the distal attachment of the PCL. It averaged 7.2 mm (range: 5.6–8.5 mm, SD: 0.77 mm) long and 2.3 mm (range: 1.3–3.0 mm, SD: 0.52 mm) wide.

Discussion

Posterolateral rotatory instability of the knee has been recognized as a significant clinical problem since it was first described in 1976 [8], but little information is known about its natural history [9]. In the human knee, the most important posterolateral knee structures, based on biomechanical studies, to preventing abnormal joint motion are the FCL, popliteus tendon, and PFL [4,5,24]. These structures act as the primary stabilizers to preventing abnormal varus and tibial external rotation motion, and serve an important secondary role to the cruciate ligaments in preventing anterior and posterior translation of the knee [4,5]. The role of individual posterolateral knee structures on preventing abnormal joint motion or their dynamic function in the rabbit knee has not been established in the literature.

The anatomy of the posterolateral aspect of the rabbit knee joint bears considerable resemblance to the human knee. While the human knee is generally accepted as being the most complex of all living animals, it bears greater hornology to the knees of animals than one would expect based on the more drastic evolutionary changes of other structures [1,7,10,23].

An important evolutionary change in the structure of the knee joint was the distal migration of the fibula compared to its relationship with the femur. In reptiles and primitive mammals from the monotreme and mar-

supial class, the fibula extends much farther proximally and articulates with the femur [1,7,17]. In the alligator, the fibulofemoral articulation even has its own meniscus [7]. In these animals the popliteus has a proximal attachment to the fibula. Through evolutionary change the fibula has moved distally to the tibiofibular articulation seen in most mammals, including rabbits and humans. In this process the popliteus tendon appears to have attained its femoral attachment [1,6,7,17,18,20].

In both species the popliteus tendon courses in a similar manner, becoming intraarticular near the lateral joint line, and inserting anterior and distal to the insertion of the FCL on the femur in a distinct groove, named the popliteal sulcus, which in humans is more distinct [3,21]. An important difference between the popliteus complex of rabbits and man which was found in this study is the absence of distinct popliteomeniscal fascicles in the rabbit. In man, the distal half of the popliteus tendon attaches to the posterolateral aspect of the lateral meniscus and has three distinct popliteomeniscal fascicles [14,15,21]. It is believed that the actions of the popliteus attachments to the lateral meniscus in humans are to retract the meniscus [14,21]. The lack of popliteomeniscal fascicles in rabbits may indicate that the function of popliteus complex is primarily for internal rotation of the tibia about the femur, similar to its function in the human knee [14,15,20], and possibly some dynamic function on the posterior capsule through its fascial attachments. This hypothesis is speculative, however, as there is no literature on the dynamic function of posterolateral structures in the rabbit.

Another important difference compared to humans with regards to the popliteus muscle complex is the lack of a distinct PFL in the rabbit. In humans, the PFL is a stout ligament coursing from the musculotendinous junction of the popliteus to attach to the posteromedial aspect of the fibular styloid [15,19,21]. It has been demonstrated that the PFL serves an important function in the knee stability of humans in preventing external rotation of the knee [13,24]. We speculate that the rabbit may not have a distinct PFL due to the bony syndesmosis of the proximal tibiofibular joint, which makes the tibia and fibula effectively function as one structure.

The FCL is a similar structure in both rabbits and humans. In both species the attachment sites are consistent with both having a femoral attachment at or close to the lateral epicondyle, and a fibular attachment to the lateral aspect of the fibular head [21]. Grossly, the ligaments appear similar, with both species having a distinct band-like FCL.

The rabbit biceps femoris muscle does not have any attachments to the FCL, fibula, or tibia like the human knee attachments to the FCL, fibular head, styloid, and proximolateral tibia [10,12,16,21,22]. Rather, the distal portion of the muscle formed a broad fascial expansion that extended from the lateral border of the patella to

attach distally to the anterior compartment of the leg and the distal portion of the lateral head of the gastrocnemius musculature. While the human biceps femur complex is felt to be an important dynamic stabilizer of the posterolateral knee through its bony and FCL attachments [21,22], the rabbit biceps femoris appears to have little, if any, dynamic role in providing stability to abnormal posterolateral motion.

Another interesting observation was the similarity in the proximal attachment and course of the human plantaris and the rabbit FDS. In both species these muscles have nearly identical attachments to the lateral fabella, leading us to suspect that they may be homologous structures [21].

The ligament of Wrisberg, one of the posterior meniscofemoral ligaments, is a prominent feature in both species, with very similar origin and insertions [21]. The ligament of Wrisberg appears to run more vertically in the rabbit, because of a slightly more proximal femoral attachment. We did not attempt to identify a ligament of Humphrey (anterior meniscofemoral ligament) in our rabbit knee dissections.

Another finding was the comparative thin posterior capsule of the rabbit knee compared to the human knee [21]. It has been observed that animals which subject their knee to certain stresses have stout ligaments to prevent instability because of those stresses [1,7,21]. If this is the case, then animals which have a primarily flexed knee posture should have thin posterior capsules. This is likely due to the fact that animals with an upright posture need sturdy posterior capsules to prevent hyperextension; a requirement not as important for animals with a flexed knee gait. This simplicity was seen in the rabbit by the lack of prominent human posterior knee structures like the oblique popliteal ligament, the fabellofibular ligament, and the PFL [11,19,21]. The thickening of the posteromedial capsule from the semimembranous tendon to the lateral sesamoid bone in the rabbit knee was suggestive of the oblique popliteal ligament of the human knee [21], but it was not a distinct stout structure.

The bony anatomy of the rabbit includes well-developed, posteriorly oriented femoral condyles, a deep intercondylar notch, and a posteriorly sloping tibial plateau, with a convex lateral tibial plateau which slopes posteriorly and laterally. These are also general features of the human knee, although the posterior and lateral slope of the lateral tibial plateau in rabbits is more pronounced. Compared to man, the rabbit has a more distinct trochlear groove with prominent ridges that extend far proximally. In the human knee, the lateral femoral condyle is broader, whereas in the rabbit, the medial femoral condyle is the larger of the two. Man appears to be the only mammalian species with a larger lateral femoral condyle. Even close ancestors such as the gorilla have a larger medial condyle [25]. This, along with the fact that during fetal development the medial condyle is larger suggests that the large lateral condyle is a recent evolutionary event and may correspond to the acquisition of erect posture [1].

In each rabbit knee we dissected, three ossified sesamoid bones were found. The popliteus contained a sesamoid bone, the cyamella, at its musculotendinous junction. The cyamella is only rarely seen in humans. Parsons [17] concluded that ossified cyamella occur in less than 1% of human knees. We also found both medial and lateral fabellae in each rabbit. Descriptions of a medial fabella in humans are very rare [18]. In humans, the incidence of a lateral fabella has been somewhat confusing because it is unclear whether authors are referring to ossified fabella or cartilaginous analogues. Ossified lateral fabella are reported to occur in 8–20% of human knees [11,18,21] with cartilaginous lateral fabellae occurring in the remainder [21].

The location and attachments of the lateral fabella are very similar in humans and rabbits. In the rabbit the lateral fabella serves as the attachment for the FDS, the lateral head of the gastrocnemius muscle, and the posterior capsule. In the human knee, the fabella is also intraarticular and intimately involved with the posterior joint capsule. It serves as an attachment site for the lateral gastrocnemius tendon, plantaris muscle, and oblique popliteal ligament [21]. In humans, when there is an ossified lateral fabella, there is usually a more distinct fabellofibular ligament [2,11]. We were unable to find a fabellofibular ligament in the rabbit.

Conclusion

Our investigation into the anatomy of the rabbit posterolateral knee anatomy has yielded important information about the individual structures and the relationships among these structures. It was found that the comparative anatomy of the rabbit knee to the human knee is similar, especially for the popliteus tendon, fibular collateral ligament, and bony anatomy. This information will prove useful for future in vivo studies for the natural history of posterolateral knee injuries and potentially for comparing surgical procedures of the posterolateral knee in rabbits to those currently performed in humans.

Acknowledgements

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