9 Muscles and Tendons

Nicolae Bolog, Gustav Andreisek, and Erika Ulbrich

9.1 Anatomy and Normal MRI Appearance

The muscle groups around the knee have an antigravity role and offer knee stabilization during standing position and stability in a variety of different positions. They can be classified based on their anatomic location as well as on their function. The muscles of the thigh and lower leg are comprised of compartments defined as distinct anatomical spaces bordered by fascia or bone. The knowledge of the anatomical boundaries of the compartments is important especially when describing the extension of the soft tissue tumors (e.g., extra- or intracompartmental). The anterior compartment of the thigh is represented by the quadriceps muscle, the sartorius, and the tensor fascia latae. The posterior compartment includes the hamstring muscles (the semitendinosus, the semimembranosus, and the biceps femoris). The medial compartment contains the gracilis and the adductor muscles. The gastrocnemius muscles are included together with the soleus muscle in the superficial posterior compartment of the lower leg.

Functionally, the muscles can be divided into four groups, which produce knee flexion (biceps femoris, semitendinosus, semimembranosus, gracilis, sartorius, and popliteus muscle), knee extension (quadriceps femoris and tensor fasciae latae), internal rotation (popliteus, semitendinosus, semimembranosus, sartorius, gracilis, and medial head of gastrocnemius muscle), or lateral rotation (biceps femoris and the lateral head of the gastrocnemius muscle). Another possibility is to distinguish the muscles around the knee based on their topography. This approach enables an easier interpretation of the MR examination with the muscles classified into three groups: the anterior, the posteromedial, and the posterolateral group.

The normal MR signal intensity of the muscles around the knee is, as with all muscles, intermediate between the signal intensity of fat and cortical bone (Fig. 9.1). The MRI signal intensity differences between the hyperintense thin intermuscular fat planes and the muscle tissue enable the separation between individual muscles or groups of muscles. The tendons appear mainly as hypointense structures in most MR sequences (Fig. 9.1).

9.1.1 The Anterior Muscle Group

The anterior muscle group of the knee or the quadriceps group includes *the vastus lateralis*, *the vastus medialis*, *the vastus intermedius*, and *the rectus femoris* (Fig. 9.2). The quadriceps muscle and tendon extend the lower leg and play an important role in patellar stability. The muscle is also an important part of the extensor mechanism of the knee, which also includes the medial and lateral patellar retinaculum, patellofemoral and patellotibial ligaments, the patellar tendon, the prepatellar structures, the Hoffa's fat pad, and the tibial tubercle.

N.V. Bolog et al., *MRI of the Knee: A Guide to Evaluation and Reporting*,
DOI 10.1007/978-3-319-08165-6_9, © Springer International Publishing Switzerland 2015

The proximal insertion of the rectus femoris is the anterior inferior iliac spine. The vastus lateralis inserts proximally to the greater femoral trochanter and the vastus medialis inserts to the femoral intertrochanteric line. The vastus intermedius has its proximal insertion along the proximal anterolateral two thirds of the femoral diaphysis. Distally, the four muscular elements of the quadriceps converge and fuse 2 cm above the patella to form the quadriceps tendon and inserts on the superior pole of the patella [1]. On MR imaging, the normal quadriceps tendon has a striated appearance with two or three layers in most of the cases (Fig. 9.3) [2]. The superficial layer is formed by the rectus femoris, the intermediate layer is represented by the vastus medialis and vastus lateralis, and the deep layer is formed by the vastus intermedius. The tendon can very rarely be identified on MR images as a homogeneously hypointense structure [1, 2].

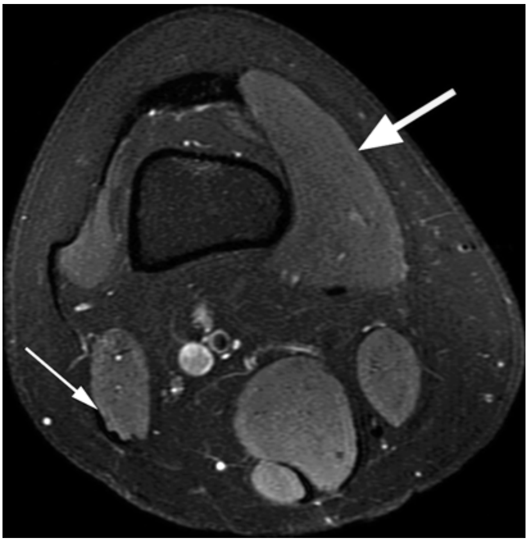

Fig. 9.1 Normal MRI appearance of muscles and tendons in a 33 year old female. Axial proton-density (PD) fat-suppressed image shows the intermediate signal intensity of the muscle (between the signal intensity of fat and cortical bone) (*large arrow* indicating the vastus medialis muscle). The tendons appear as hypointense structures (*small arrow* indicating the tendon of the biceps femoris)

9.1.2 The Posteromedial Muscle Group

The posteromedial group of muscles consists of the *sartorius*, *gracilis*, *semitendinosus*, *semimembranosus*, and *medial gastrocnemius*.

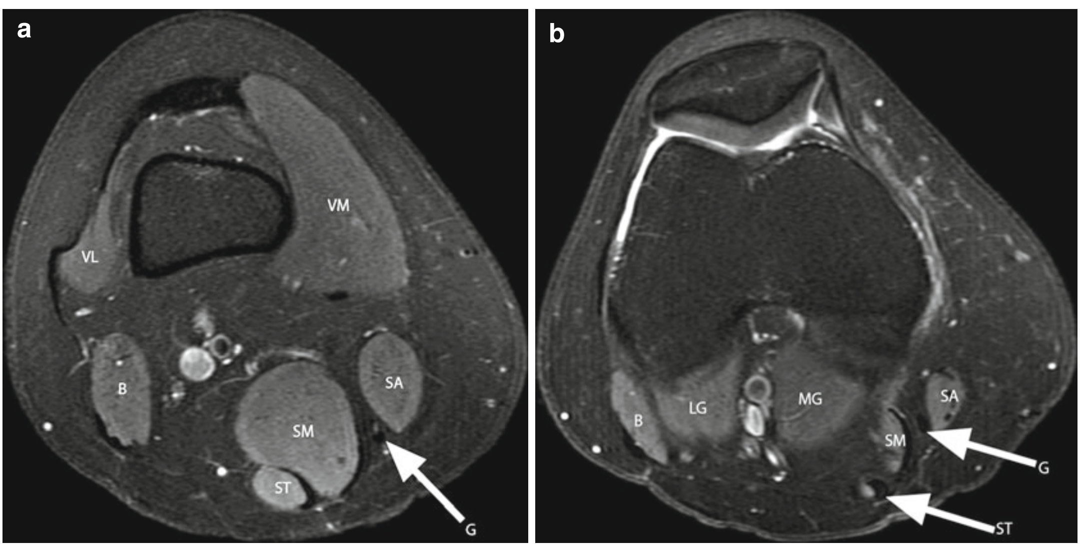

Fig. 9.2 Axial proton-density (PD) fat-suppressed image 8 cm above the joint line (**a**) and 3 cm above the joint line (**b**) shows the vastus medialis (*VM*) and vastus lateralis (*VL*). The posteromedial group of muscles consists of the sartorius (*SA*), gracilis (*G*), semitendinosus (*ST*), semimembranosus (*SM*), and medial gastrocnemius (*MG*). The biceps femoris muscle and tendon (*B*) and the lateral head of the gastrocnemius muscle (*LG*) are part of the posterolateral muscle group

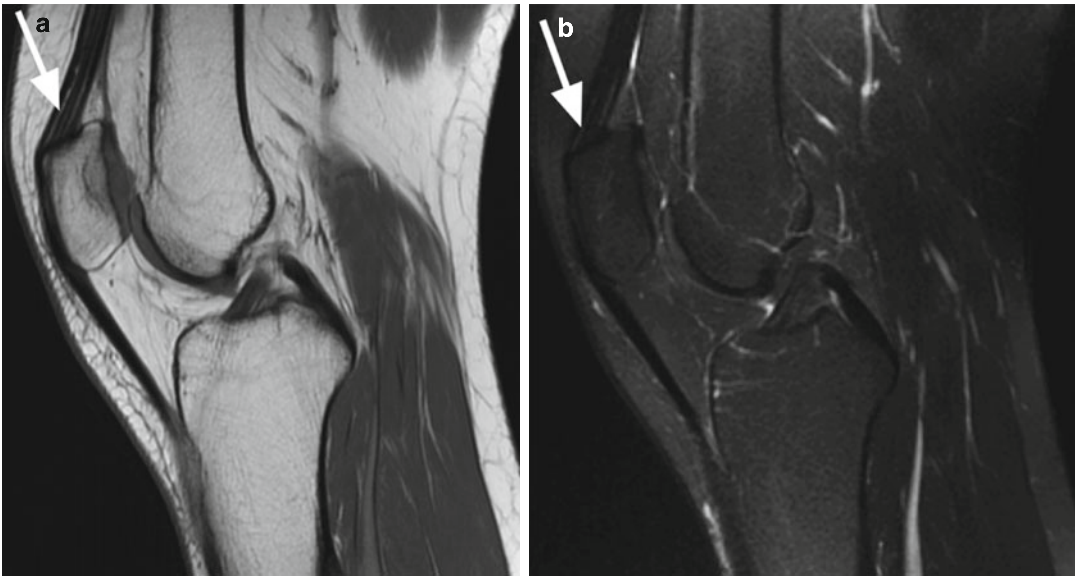

Fig. 9.3 Normal appearance of the quadriceps tendon in a 33 year old female. Sagittal proton-density (PD) image (**a**) and sagittal T2-weighted fat-suppressed image (**b**) show the three-layer appearance of the tendon (*arrows*). The superficial layer is formed by the rectus femoris, the intermediate layer is represented by the vastus medialis and vastus lateralis, and the deep layer is formed by the vastus intermedius

The proximal insertions of the *sartorius*, *gracilis*, and *semitendinosus* are the anterior superior iliac spine (sartorius), inferior pubic ramus (gracilis), and ischial tuberosity (semitendinosus). The semitendinosus tendon has a common ischial insertion with the biceps femoris muscle. The distal parts of the sartorius, gracilis, and semitendinosus tendons converge into the *pes anserinus* and insert to the proximal anteromedial tibia. The sartorius muscle is the most medially located muscle (Fig. 9.2). Lateral to the former is the gracilis muscle and its tendon (Fig. 9.2). The semitendinosus muscle is located posterolateral to the gracilis muscle and posterior to the semimembranosus muscle (Fig. 9.2). Between the pes anserinus and the medial collateral ligament, there is the pes anserinus bursa, which typically does not communicate with the knee joint. The three muscles and the pes anserinus contribute to knee flexion and internal rotation.

The semimembranosus muscle is the largest of the posteromedial group and originates from the ischial tuberosity and extends to the posteromedial tibial condyle below the articular surface. The proximal, ischial insertion of the semimembranosus is located just lateral to the common insertion of the semitendinosus and biceps femoris. The three muscles are known as the hamstring complex or the hamstring muscles. They extend the thigh and flex and rotate the lower leg. At the level of the knee joint, the semimembranosus tendon reinforces the posteromedial corner of the knee. On axial MR images, the semimembranosus muscle is located between the medial head of the gastrocnemius muscle and the gracilis muscle (Fig. 9.2). Between the semimembranosus tendon and the medial collateral ligament of the knee, there is the medial collateral-semimembranosus bursa. Between the semimembranosus muscle and tendon and the medial head of the gastrocnemius muscle, there is the gastrocnemius-semimembranosus bursa. The semimembranosus muscle flexes the knee and contributes to internal rotation.

The medial head of the gastrocnemius muscle plays also an important role in reinforcing the posteromedial corner of the knee. It inserts to the medial condyle and posterior surface of the femur and extends to the Achilles tendon (Fig. 9.4). The medial posterior femoral recess (the medial

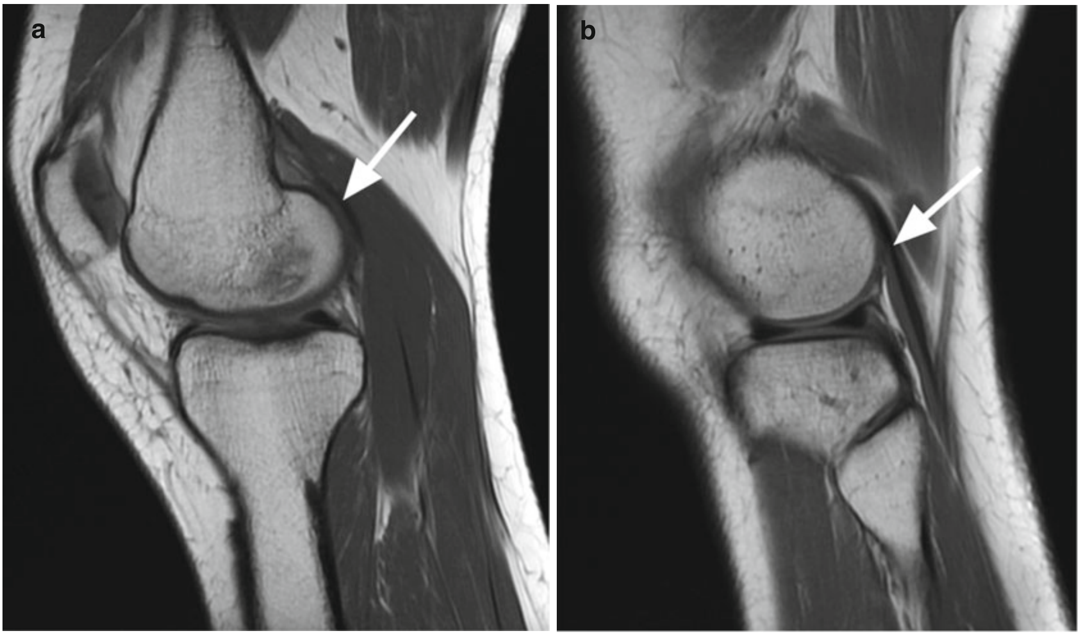

Fig. 9.4 Proximal insertions of medial and lateral gastrocnemius muscles. Sagittal proton-density (PD) image through the medial compartment (**a**) shows the medial tendon and musculotendinous junction of the medial gastrocnemius muscles (*arrow*). Sagittal proton-density (PD) image through the lateral compartment (**b**) shows the tendon of the lateral gastrocnemius muscles (*arrow*)

gastrocnemius bursa) is located between the posterior horn of the medial meniscus and the knee capsule and the medial head of the gastrocnemius muscle, respectively. This bursa may or may not communicate with the knee joint. The gastrocnemius muscle flexes the lower leg and contributes to internal rotation.

9.1.3 The Posterolateral Muscle Group

The posterolateral group is formed by the *iliotibial band*, *biceps femoris*, *popliteus*, *plantaris*, *and the lateral head of the gastrocnemius muscle* (Fig. 9.2).

The iliotibial band or the iliotibial tract represents a thickening of the fascia lata, which extends from the outer margin of the anterior iliac crest down to the Gerdy's tubercle and to the head of the fibula (Fig. 9.5). A portion of fascia lata known as the anterior longitudinal expansion merges with the anterior quadriceps aponeurosis, forms the intermediate layer of the lateral retinaculum, and attaches to the patella [3]. The fascia lata is considered an anterolateral knee stabilizer and is tense in both flexion and extension of the knee [4].

The biceps muscle is one of the three muscles that form the hamstring complex. The long head of the biceps femoris inserts proximally together with the semitendinosus muscle on the ischial tuberosity. The short head of the biceps has its proximal insertion on the linea aspera and the lateral supracondylar line. Distally, the biceps muscle joins the lateral collateral ligament and forms a conjoined tendon that inserts on the fibular head (Fig. 9.6). The biceps tendon is seen on axial MR images posterior to the iliotibial band and the lateral collateral ligament (Fig. 9.6). Between the biceps tendon and the lateral collateral ligament, the lateral collateral ligament-biceps femoris bursa is constantly described [5]. The biceps femoris contributes to the lateral stabilization of the knee and to the external rotation of the tibia.

The popliteus muscle inserts on the lateral femoral condyle above the superior margin of the lateral meniscus, distal and anterior to the lateral

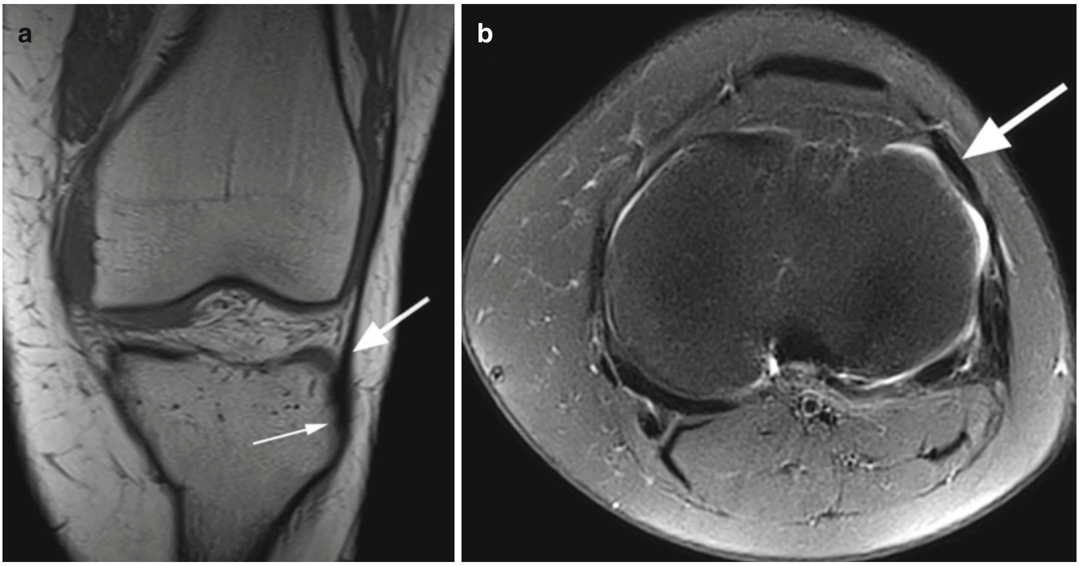

Fig. 9.5 Iliotibial band in a 27 year old female. Coronal T1-weighted image (**a**) and axial proton-density (PD) fat-suppressed image (**b**) show the distal iliotibial band (*large arrow* in **a**, **b**) and the insertion on the Gerdy's tubercle (*small arrow* in **a**)

collateral ligament (Fig. 9.7) [6, 7]. Two separate bundles are described at the proximal attachment: the posterior superficial bundle and the anterior deep bundle. Laterally, the muscle joins the arcuate ligament of the knee capsule (Fig. 9.8). The tendon passes through a hiatus in the coronary ligament, crosses obliquely deep to the lateral collateral ligament, and becomes extra-articular. It inserts to the posteromedial surface of the tibial metaphysis (Fig. 9.7). The tendon is surrounded by the popliteal bursa [8]. At the proximal insertion, the tendon creates a sinusoidal indentation of the cartilage at the border of the lateral femoral condyle called sulcus statarius of Furst, and the tendon slides into this sulcus during flexion [6].

The popliteus muscle alone is responsible for knee flexion and tibial internal rotation of the tibia at the beginning of flexion. Also the popliteal tendon is an important structure of the posterolateral corner of the knee that limits posterior translation, varus angulation, and external rotation [9]. The muscle is connected to the lateral meniscus and the proximal aspect of the fibula. The connection between the medial part of the muscle and the lateral meniscus is ensured by the posterosuperior and anteroinferior popliteomeniscal fascicles (Fig. 9.9). The popliteofibular ligament attaches the popliteus tendon to the fibular head and has a thickness similar to the lateral collateral ligament (Fig. 9.10).

The plantaris muscle has the origin on the lateral supracondylar line of the femur (Fig. 9.11), and its long distal tendon inserts on the posteromedial part of the calcaneus. The muscle has a role in flexion of the lower leg at the knee joint.

The lateral head of the gastrocnemius inserts on the lateral femoral condyle and posterior surface of the femur (Fig. 9.4) and extends to the Achilles tendon. Between the lateral head of the gastrocnemius muscle and the posterior horn of the lateral meniscus and the knee capsule, the lateral posterior femoral recess or bursa is present. Besides the role of flexion of the lower leg at the knee joint, it also contributes to lateral rotation.

9.1.4 Anomalous Knee Muscles

Anomalous Gastrocnemius Muscles

Anomalous gastrocnemius variations are very rare and may involve the medial or the lateral

Fig. 9.6 Distal biceps tendon in a 40 year old male. Two coronal proton-density (PD) images through the posterior joint (**a**, **b**) show the distal tendon (*arrow* in **a**) and the insertion on the fibular head (*arrow* in **b**). At the insertion the tendon forms a conjoined tendon with the lateral collateral ligament (LCL). Axial proton-density (PD) fat-suppressed image (**c**) shows that the biceps tendon (*large arrow*) is seen posterior to the lateral collateral ligament (LCL) (*small arrow*) and to the iliotibial band (*curved arrow*)

head of the gastrocnemius. On the medial side, a known variation is a third gastrocnemius head. On the lateral side, possible variations include the origin and the number of muscle bundles.

The medial variation is commonly known as *the third head of the gastrocnemius muscle*. It has been described in adults in the setting of popliteal artery entrapment syndrome [10, 11]. If present, the anomaly refers to an accessory third gastrocnemius head which is more medial than the normal medial head.

A medial accessory origin of a segmental bundle of the lateral gastrocnemius head has also been described [12]. In this case, the accessory gastrocnemius bundle originates from the iliotibial tract [12]. *In medial accessory anomalous origin of the lateral gastrocnemius head*, an accessory bundle

Fig. 9.7 Popliteus muscle in a 40 year old male. Coronal proton-density (PD) image (**a**) and axial proton-density (PD) fat-suppressed image (**b**) show the proximal insertion to the lateral femoral condyle (*large arrows* in **a**, **b**). The insertion is distal and anterior to the lateral collateral ligament (*small arrows* in **a. b**). Coronal proton-density (PD) image (**c**) shows the normal area of the popliteus muscle including its distal part adjacent to the posteromedial surface of the tibial metaphysis

originates from the posterior and medial aspect of the lateral femoral condyle, lateral to popliteal vessels, which then merges with the medial aspect of the lateral head of the gastrocnemius.

On MR imaging, the variations of the gastrocnemius are best identified on axial images. It remains particularly difficult to assess the anomalies on coronal or sagittal planes. Almost half of the patients may present chronic nontraumatic pain with no additional MR imaging findings [12]. Thus, in cases where no other findings are present, one might always think about normal anatomical variants. The etiology of the pain may be ischemic due to popliteal artery entrapment or due to compression and/or impaired nerve function. For the latter, evaluation of the tibial and peroneal nerve is mandatory.

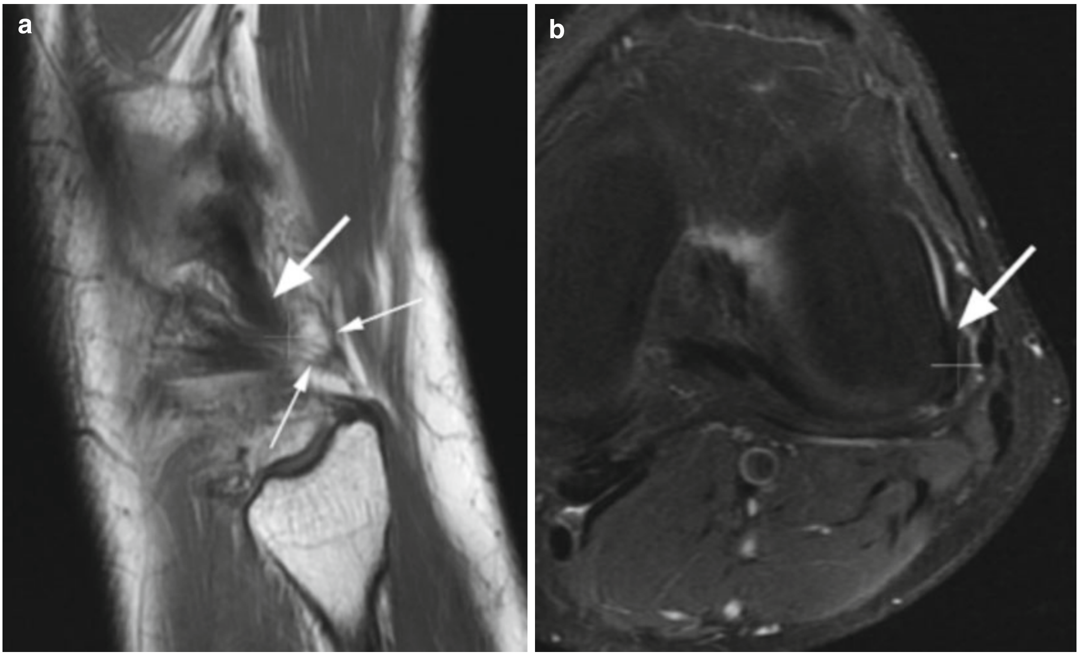

Fig. 9.8 Popliteus muscle and arcuate ligament in a 40 year old male. Sagittal proton-density (PD) image (**a**) and axial proton-density (PD) fat-suppressed image (**b**) show the popliteal tendon (*large arrows* in **a**, **b**) joining and the arcuate ligament (*small arrow* in **a**) at the level of posterolateral capsule (cross in **a**, **b**)

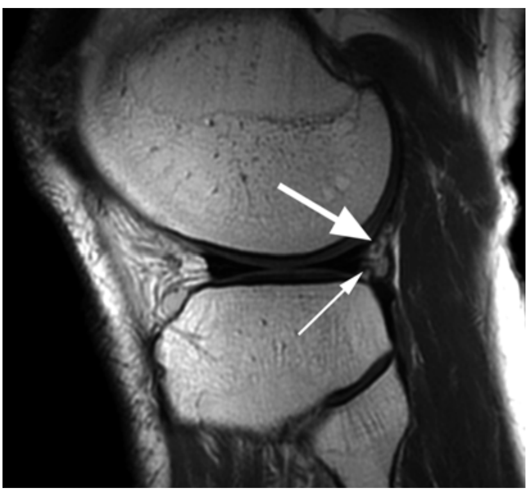

Fig. 9.9 Popliteomeniscal fascicles in a 56 year old male. Sagittal proton-density (PD) image shows the connection between the popliteus muscle and the lateral meniscus ensured by the posterosuperior (*large arrow*) and anteroinferior popliteomeniscal fascicles (*small arrow*)

Tensor Fascia Suralis Muscle

The tensor fascia suralis muscle originates in the majority of cases from the distal semitendinosus muscle and inserts into the posterior fascia of the lower leg, into the medial head of the gastrocnemius, or via a long and thin tendon onto the Achilles tendon [13, 14]. The muscle is situated superficially between the semimembranosus and semitendinosus.

Accessory Popliteus Muscle

This accessory muscle has a common origin with the lateral head of the gastrocnemius and inserts distally to the posteromedial capsule [14]. The muscle is seen on axial MR images within the popliteal fossa anterior to the popliteal vessels and nerves and may be of clinical significance in the cases of vascular compression.

9.2 MRI Pathological Findings

9.2.1 Traumatic Injuries: General Findings

MR imaging is the best imaging choice for the assessment of the muscles and tendons around

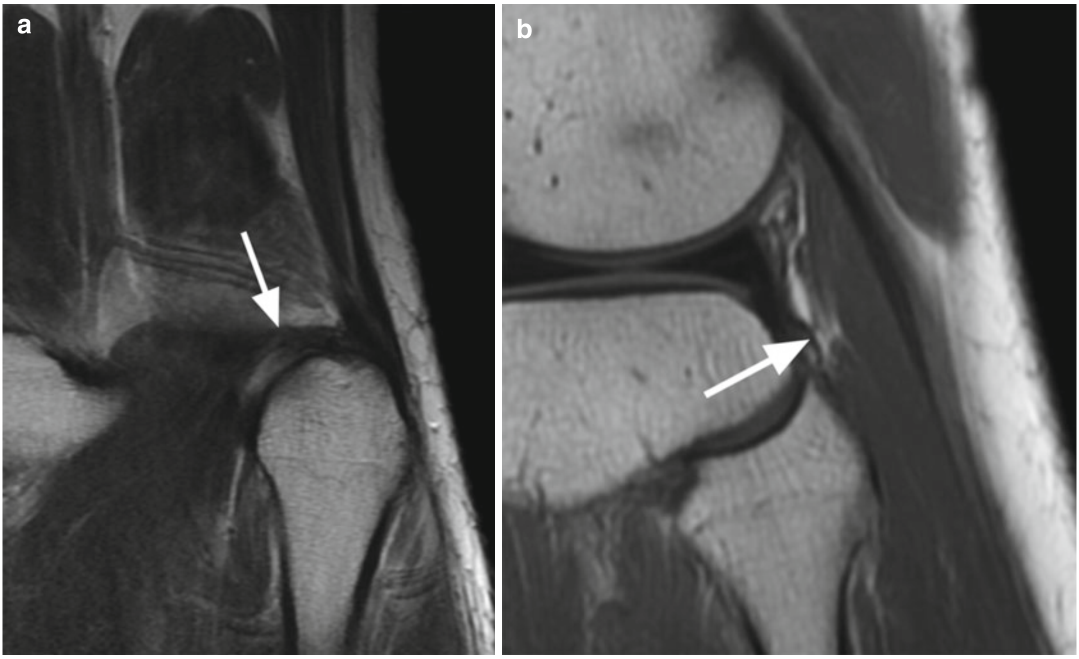

Fig. 9.10 Popliteofibular ligament in a 40 year old male. Coronal proton-density (PD) image (**a**) and sagittal proton-density (PD) image (**b**) show the popliteofibular ligament (*arrows*) connecting the popliteus tendon to the fibular head

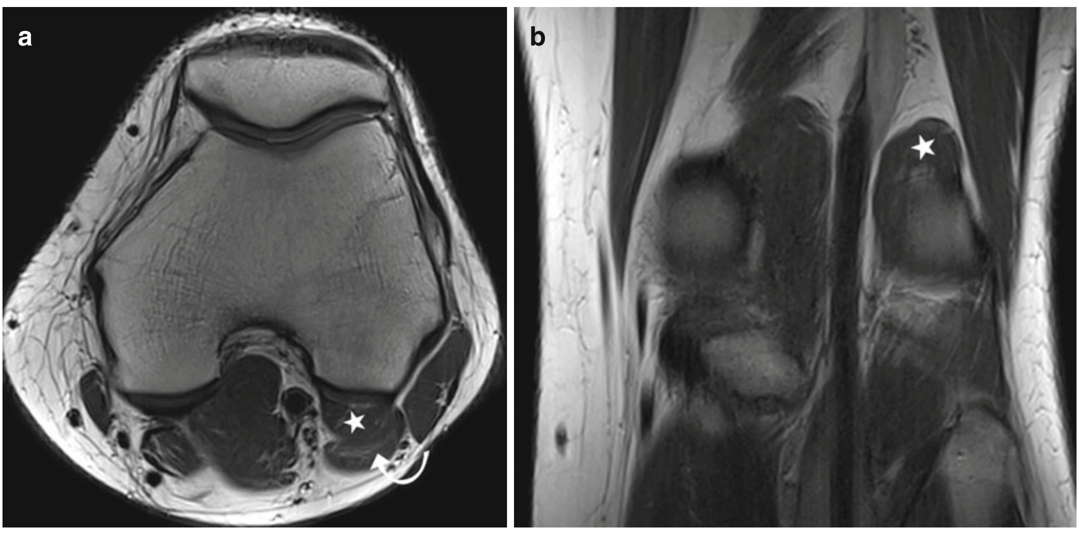

Fig. 9.11 Plantaris muscle in a 25 year old female. Axial proton-density (PD) image (**a**) and coronal proton-density (PD) image (**b**) show the plantaris muscle (*star* in **a**, **b**) originating from the posterior lateral femoral condyle. The muscle is situated at its origin anterior to the lateral gastrocnemius muscle (*curved arrow* in **a**)

the knee. In acute trauma cases, it is used to target the location, the extension, and the severity of muscle lesions. Placing a skin marker before examination (e.g., a vitamin E capsule) enables the radiologist to correlate the imaging findings with the clinical pain. A correct diagnosis is crucial for a reliable prognosis. The most common muscle injuries are contusions (direct injuries),

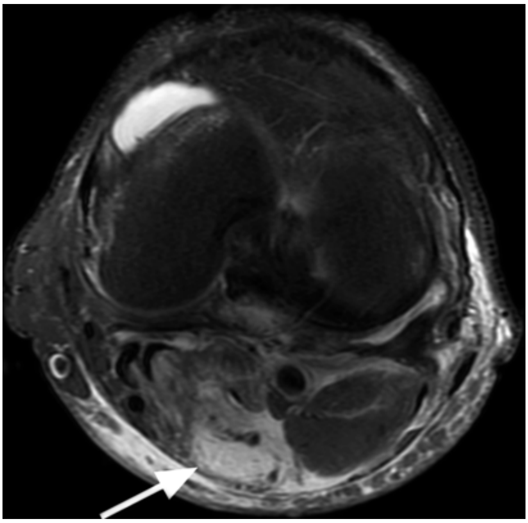

Fig. 9.12 Hematoma of the medial gastrocnemius muscle in a 51 year old male after direct muscle injury. Axial proton-density (PD) fat-suppressed image shows an ill-defined hyperintense area with fiber discontinuity indicating the intramuscular hematoma (*arrow*)

strains or tears (indirect injuries), and tendinous avulsions.

Muscular Contusions (Direct Lesions)

Muscular contusions are direct acute muscle injuries characterized by lacerations or contusions due to external forces [15, 16]. The most frequently injured muscles are the exposed rectus femoris and the vastus intermedius. Lesions can be clinically graded into mild, moderate, and severe [17]. The patient presents with pain and swelling and, occasionally, with a palpable mass. Contusions may lead to diffuse predominantly intramuscular hemorrhage with the muscle fibers displaced and compressed with or without longitudinal discontinuity. Contusions can lead to severe complications such as acute compartment syndrome, active bleeding, or large hematoma [18]. On MR imaging, the lesions appear as an ill-defined hyperintense area on T2-weighted images with or without fiber discontinuity (Fig. 9.12) or as a well-circumscribed intramuscular hematoma (Fig. 9.12). Intramuscular hematoma displays a homogeneous intermediate-signal-intensity pattern on T1-weighted images slightly higher than that of the normal muscle. Rarely, T1-weighted hyperintense foci of hemorrhage may be seen. On T2-weighted images, acute or subacute hematoma appears as a high-signal-intensity mass (Fig. 9.12). In chronic phases, hematoma appears as an inhomogeneous well-circumscribed lesion on T1-weighted images with hyperintense foci and peripheral hypointense hemosiderin. After contrast administration, chronic hematomas may enhance at the periphery. On T2-weighted images and T2*-weighted images, hematomas are inhomogeneous and hyperintense with areas of low signal intensity and susceptibility artifacts due to blood degradation and heterotopic calcifications. Chronic intramuscular hematomas may mimic the appearance of soft tissue tumors (e.g., sarcomas). Intramuscular hematomas often resorb over a period of 6–8 weeks [19].

A complication associated with severe contusions is *myositis ossificans*, a benign proliferation of bone and cartilage in the area of contusion [16]. The reported incidence of myositis ossificans is between 9 and 17 % and should be suspected in any patient in which the symptoms worsen after 2–3 weeks accompanied by loss of functionality and persistent swelling [16, 17, 20]. Early-on myositis ossificans lesions consist of a non-ossified core of benign fibroblasts and myofibroblasts, with a minor component of osteoid and mature lamellar bone at the periphery [21]. In intermediate phases, myositis ossificans lesions are found to be surrounded by mature lamellar bone with no fibroblasts in the central portion [21]. Late-phase myositis ossificans lesion consists exclusively of mature lamellar bone. Intralesional hemorrhage, inflammation, and fibrosis or inflammation of the surrounding tissue may be present (Fig. 9.13) [21].

The bone component of myositis ossificans is identified on radiographs as early as 3 weeks after the injury [20]. On MR imaging, myositis ossificans appears in early and intermediate phases as an inhomogeneous high-signal-intensity mass on T2-weighted images with surrounding edema that can be present within 8 weeks of the onset of symptoms [21]. During

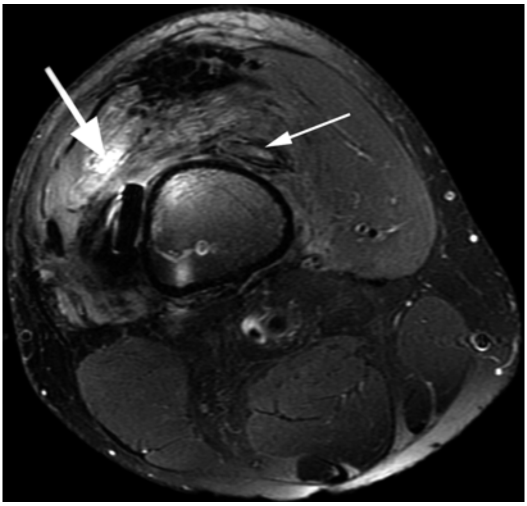

Fig. 9.13 Late-phase myositis ossificans of the quadriceps muscle in a 38 year old male. Axial proton-density (PD) fat-suppressed image shows a fibrotic indeterminate mass with hemorrhage (*large arrow*) and mature lamellar bone (*small arrow*)

these phases, it mimics a tumor. Curvilinear low-signal-intensity lesion corresponding to bone tissue may be seen within the mass. In late-phase myositis ossificans, the lesion is intermediate signal intensity on T2-weighted and T1-weighted images with peripheral low signal intensity due to calcification. Areas of fatty signal intensity and areas of decreased signal intensity due to bone formation may be seen within the lesion [21].

Strains/Tears (Indirect Lesions)

Strain is a biomechanical term, which can be used indiscriminately for anatomically and functionally different muscles and tendons [18]. However, there is no general agreement between radiologists and practitioners regarding the terminology and the definition of muscle strains and tears, and this aspect may lead to a high rate of inaccurate diagnosis or misunderstanding [18]. Use of the same classification and terminology between radiologists and clinicians is crucial to avoid premature return to full activity and the risk of reinjury [22]. We suggest the following classification system, which is based on the distinction between functional and structural muscle disorders, but encourage all radiologists to discuss its use with the referring clinicians (Table 9.1).

The functional muscle injuries are distinct clinical entities, which lead to painful limitation for the patients or athletes. The functional injuries include *fatigue-induced muscle disorder* and *delayed onset of muscle soreness*. Although the disorders are below the sensibility of standard MR imaging techniques, they are a risk factor for structural lesions [18]. It should be noted however that in some of these disorders, dedicated MR techniques, such as muscle spectroscopy, muscle diffusion (tensor) imaging, arterial spin labeling (ASL), or intravoxel incoherent motion (IVIM) imaging, might be able to show abnormalities in the future. For now, however, these techniques are only used for research and not applicable in the clinical routine.

The term *tear* is used for *structural muscle injuries* and macroscopically damages to the muscle structure. They are easily demonstrated on MR imaging, and they can be classified based on the affected diameter of the muscle (Table 9.1). The lesions lead to loss of continuity of muscle fibers and bundles. As a result, there is a loss of contractile properties of the muscle [18].

MR imaging can aid in the investigation of acute muscle injuries in predicting recovery time based on the size, the location, and the grade of the acute traumatic muscle lesion, and all these MRI findings should be described in the MRI report in detail. Since there are no consensus guidelines or agreed-upon MRI and clinical criteria for safe return to sport following muscle injuries, the detailed MR imaging findings are generally used to assist in determining prognosis for initial injury rather than a screening for return to activity [23].

Tendinous Avulsions (Indirect Lesions)

Tendinous avulsions are indirect injuries that implies the detachment of a bone fragment from pulling away the tendon from its insertion (Fig. 9.20). Avulsions fractures around the knee are discussed in Chap. 11.

Table 9.1 Classification and MR imaging of acute muscle injuries

Classification		Definition	Clinical manifestations	MR imaging
Functional disorders	Fatigue-induced muscle disorder	Increase of muscle tone due to overexertion	Aching muscle; can provoke pain at rest	Negative
	Delayed-onset muscle soreness	More generalized pain following unaccustomed movements	Acute pain; pain at rest after activity	Negative or diffuse high-signal-intensity edema[a]
Structural lesions or tears	Minor partial tear (Figs. 9.14 and 9.15)	Injury involving a maximum diameter of less than a muscle fascicle/bundle	Sharp pain at time of injury	Fiber disruption; diffuse edema[b] and possible small intramuscular hematoma[c]
	Moderate partial tear (Fig. 9.16)	Injury involving more than a muscle fascicle/bundle	Sharp pain at time of injury; possible defect at palpation	Significant fiber disruption; may include fiber retraction; diffuse edema[b] and intramuscular hematoma[c]
	Subtotal muscle/tendon tear (Fig. 9.17)	Tear involving more than 50 % of the muscle or tendon diameter	Dull pain at time of injury; large defect at palpation	Discontinuity involving more than 50 % of the muscle or tendon diameter; possible wavy tendon and retraction; intramuscular hematoma[c]
	Complete muscle/tendon tear (Figs. 9.18 and 9.19)	Complete disruption of the muscle or tendon	Dull pain at time of injury; possible fall at time of accident; palpable defect	Complete discontinuity of the muscle or tendon; wavy tendon and muscle retraction; intramuscular hematoma[c]

Modified after Mueller-Wohlfahrt et al. [18]
[a]Diffuse hyperintense muscle on T2-weighted images
[b]Ill-defined, feathery hyperintensity on T2-weighted images intermuscular and between the muscle fibers/bundles
[c]Intramuscular diffuse or well-delineated intermediate-signal-intensity lesion on T1-weighted images and high signal intensity on T2-weighted images

9.2.2 Traumatic Injuries: Clinical and Imaging Findings of Specific Muscles Around the Knee

Anterior Muscle Group Injuries (Quadriceps Muscle and Tendon)

Partial or complete tear of the quadriceps occurs frequently in sports activities and may appear anywhere in the distal part of the muscle. Most commonly, it involves the tendon of the vastus intermedius and the myotendinous junction of the rectus femoris muscle. Repetitive trauma or strong deceleration may result in tears of the quadriceps tendon above the patellar insertion or acute avulsion at the patellar insertion [24]. Spontaneous tears occur in degenerated or weakened quadriceps muscle tendons (Fig. 9.21). Underlying causes include gout, diabetes, hyperparathyroidism, and collagen vascular diseases [25].

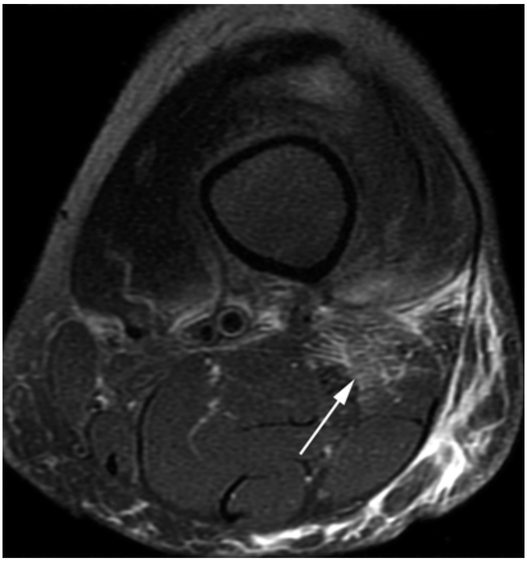

Fig. 9.14 Minor partial tear of the biceps muscle in a 48 year old female. Axial proton-density (PD) fat-suppressed image shows diffuse edema in the muscle (*arrow*) without fiber discontinuity and without hematoma

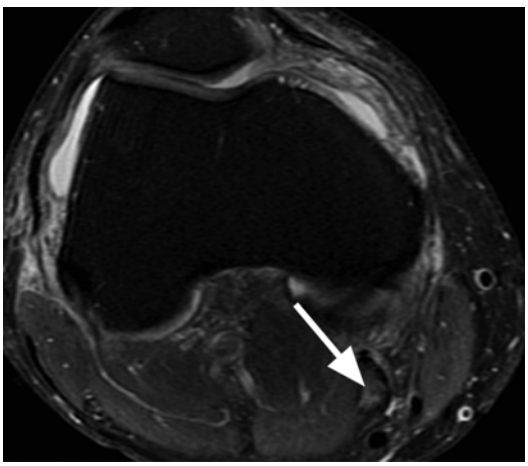

Fig. 9.15 Minor partial tear of the semimembranosus muscle in a 45 year old female. Axial proton-density (PD) fat-suppressed image shows a small hematoma in the semimembranosus muscle (*arrow*) involving less than a muscle fascicle

Posteromedial Muscle Group Injuries

The distal tendons of the *sartorius*, *gracilis*, *and semitendinosus* muscles converge into a common insertion constituting the so-called pes anserinus. The sartorius muscle is commonly susceptible to injuries due to its superficial location [25]. *Pes anserinus tendino-bursitis* is a syndrome characterized by spontaneous medial knee pain with tenderness in the inferomedial aspect of the joint [26]. The syndrome may appear in runners as well as in patients with rheumatoid arthritis or osteoarthritis. Diabetes mellitus is also a known predisposing factor for this syndrome [26].

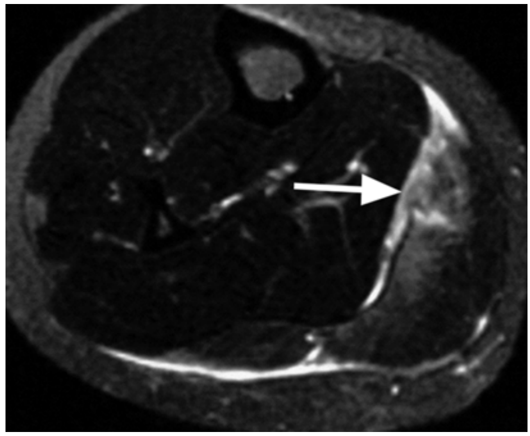

Fig. 9.16 Moderate partial tear of the medial gastrocnemius muscle. Axial T2-weighted fat-suppressed image shows diffuse high-signal-intensity changes which involve more than a muscle fascicle/bundle (*arrow*)

Injuries to the *semimembranosus tendon* (Fig. 9.15) can lead to muscle or tendon tears or to avulsion fractures at the insertion. Semimembranosus tendon tears are commonly associated with tears of the origin of the medial head of the gastrocnemius tendon especially in patients with posteromedial instability [25]. Avulsion injury of the insertion of the semimembranosus tendon results from a valgus stress to the knee and is usually associated with anterior cruciate ligament tears and tears of the posterior horn of the medial meniscus [27].

Traumatic injuries to *the medial head of the gastrocnemius muscle* may appear in combination with a rupture of the soleus and/or plantaris muscle or can be isolated and are then referred to as “tennis leg” [25, 28, 29]. The injuries are usually located at the proximal or midportion of the lower leg.

Posterolateral Muscle Group Injuries

Iliotibial band syndrome (*iliotibial friction syndrome*) is the most common cause of lateral knee symptoms in runners, with an incidence from 1.6

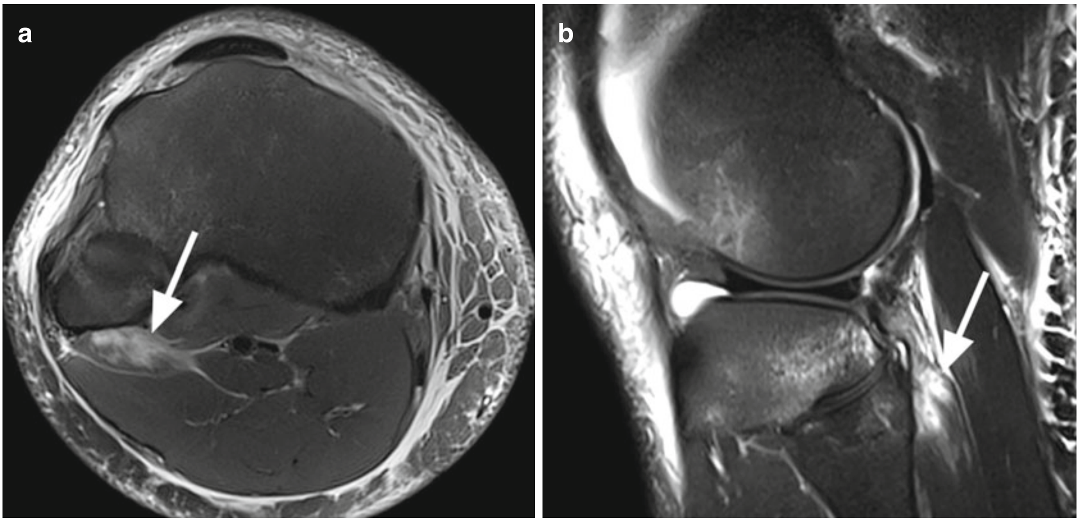

Fig. 9.17 Subtotal soleus muscle in a 21 year old male. Axial proton-density (PD) fat-suppressed image (**a**) and sagittal T2-weighted fat-suppressed image (**b**) show diffuse edema and hematoma (*arrow*) involving more than 50 % of the soleus muscle

to 12 % [30–34]. The syndrome was also reported in rowers, skiers, and soccer and hockey players [33, 35, 36]. The patient present initially with pain to the region of the distal iliotibial band and, as the condition worsens, with pain at rest [37]. The etiology is debatable. The most common theories include the friction of the iliotibial band against the lateral femoral condyle and chronic inflammation of the iliotibial bursa [37]. However, studies using histological examinations of cadaver knees and patients concluded that iliotibial band syndrome is a "fascia lata compression syndrome" of the highly vascularized and innervated adipose tissue beneath the iliotibial band [38]. The MR imaging findings include poorly defined soft tissue edema of low signal intensity on T1-weighted images and high signal intensity on T2-weighted images in the fatty tissue deep to the iliotibial band (Fig. 9.22) [39]. The signal alteration may extend into the fatty tissue distal to the vastus lateralis and into the area between the iliotibial band and the biceps femoris muscle [39]. Thickening of the iliotibial band is seen especially in subacute and chronic stages. Circumscribed fluid collections are present in a minority of patients, but the differentiation between this bursa-like reactive appearance and a true bursa is difficult [39, 40]. In some cases, discrete bone marrow edema involving the lateral femoral condyle adjacent to the iliotibial band can be identified on coronal MR images.

Being a lateral stabilizer of the knee, partial or complete tear of the iliotibial band may be seen on MR images in patients with acute posterolateral instability [25].

The mechanism of injury of the posterolateral corner of the knee is involved in *the biceps tendon and popliteus tendon and muscle* injuries (e.g., direct varus force to the anteromedial aspect of the hyperextended knee). Isolated biceps tendon (Fig. 9.23) and popliteal muscle injuries are very rare since almost 90 % of the patients with posterolateral injuries have multiligamentous injuries [41]. The popliteus tendon is involved in more than two thirds of the patients, and the biceps tendon is involved in more than one third of the patients with posterolateral corner injuries [41]. It is critical, however, to recognize all lesions of the structures that are involved in patients with posterolateral stability.

Injuries of the muscle and myotendinous junction are the most common injuries of the popliteus

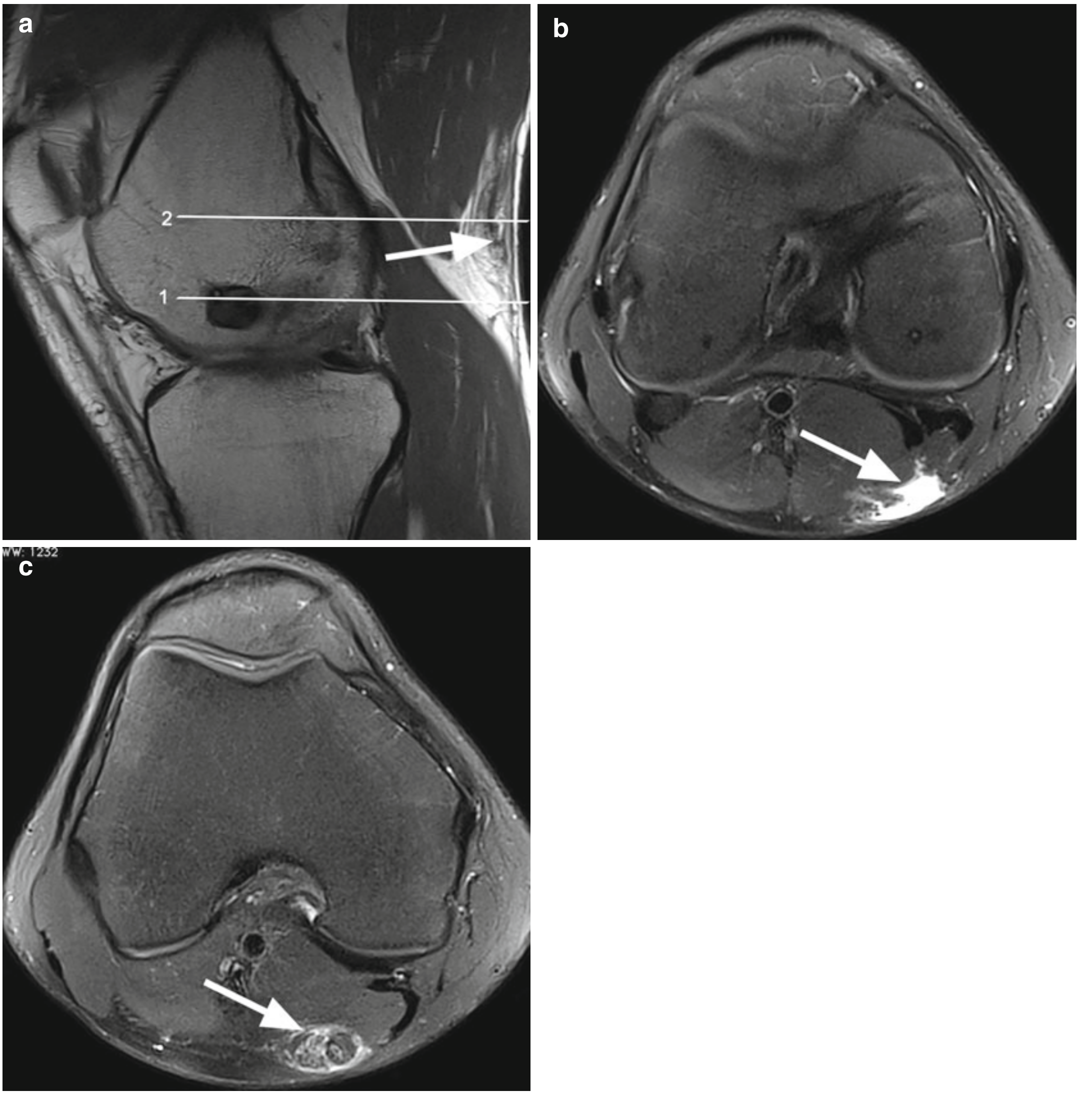

Fig. 9.18 Complete tear of the biceps tendon in a 25 year old male. Sagittal proton-density (PD) image (**a**) shows complete disruption of the biceps tendon with tendon retraction (*arrow*). Axial proton-density (PD) fat-suppressed image (**b**) through a plane caudally to the retracted tendon (*line* 1 in **a**) shows the presence of hematoma and the absence of the tendon at this level (*arrow*). Axial proton-density (PD) fat-suppressed image (**b**) obtained more cranially (*line* 2 in **a**) shows the retracted tendon with surrounding edema (*arrow*)

(Fig. 9.24) [42]. Avulsion fractures of the popliteus or the biceps tendon may be present, and the diagnosis is based on the identification of the donor site and the avulsed bone fragment. MR imaging is superior to radiographs and clearly demonstrates both the donor site and the bone fragment. This is especially useful in the cases in which the differential diagnosis between avulsion of the biceps tendon or the arcuate sign is equivocal on radiography (Fig. 9.20) [43].

Rupture of *the plantaris muscle* usually occurs at the myotendinous junction with or without an associated hematoma. A proximal injury of the plantaris muscle may occur as an isolated injury

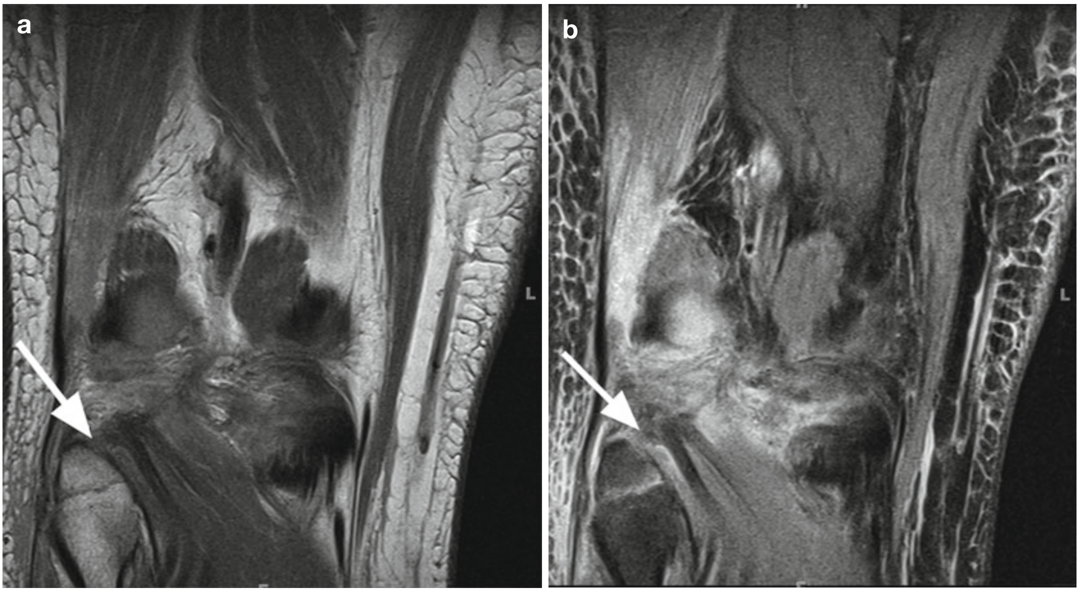

Fig. 9.19 Tear of popliteofibular ligament. Coronal proton-density (PD) image (**a**) and coronal T2-weighted fat-suppressed image (**b**) show a complete tear of the popliteofibular ligament with small hematoma at the fibular insertion (*arrow*)

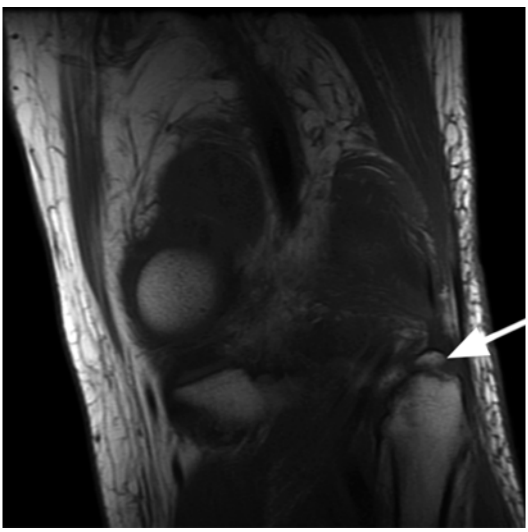

Fig. 9.20 The arcuate sign in a 51 year old male. Coronal proton-density (PD) image shows a detached bone fragment from the fibular head (*arrow*) resulting from biceps tendon avulsion

after a forceful contraction of the muscle, but in most of the cases, it is accompanied by partial tear of the medial head of the gastrocnemius muscle, tear of the anterior cruciate ligament, or posterolateral corner injuries [29].

Tears of *the lateral head of the gastrocnemius* muscle occur in patients with injuries that lead to posterolateral corner instability and are usually involved together with the popliteus tendon, biceps tendon, and plantaris muscle [25].

9.2.3 Intratendinous and Peritendinous Ganglion Cyst

Intratendinous ganglion cysts are uncommon lesions, but a correct diagnosis is necessary for differentiation from other pathologies and for a proper treatment modality [44]. Although ganglion cyst are usually painless, when symptomatic, they cause pain, local edema, and inflammation. Intratendinous ganglion cysts around the knee were reported in the tendon of the quadriceps muscle, semimembranosus muscle, and patellar tendon [44–46]. Repetitive trauma to the tendon with subsequent cystic degeneration or a congenital anomaly of the tendon in patients without trauma may be responsible for the intratendinous and peritendinous cyst

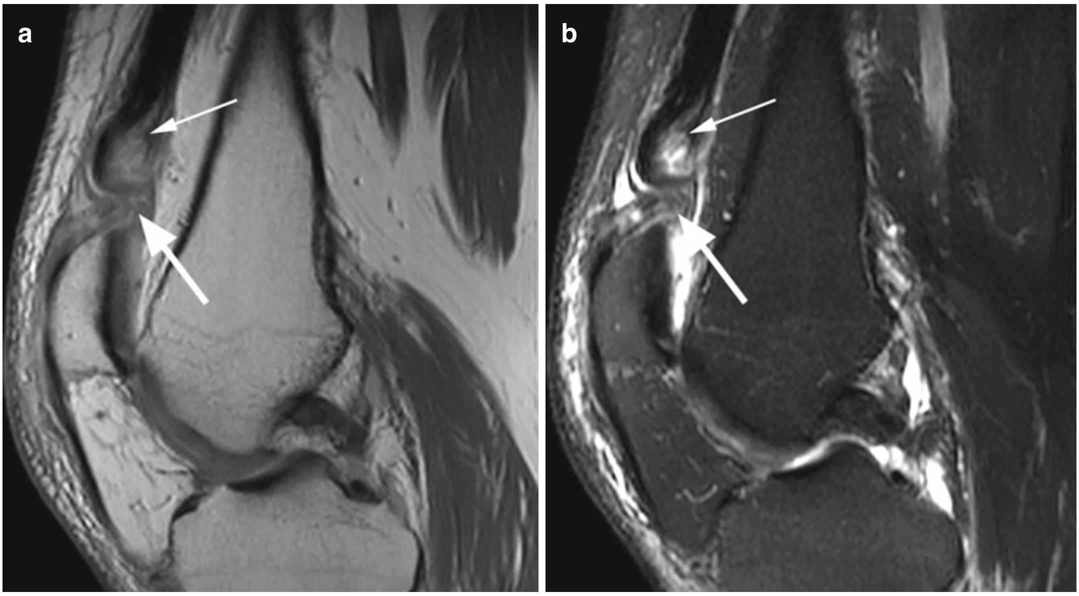

Fig. 9.21 Complete quadriceps tendon tear in a 63 year old male. Sagittal proton-density (PD) image (**a**) and sagittal T2-weighted fat-suppressed image (**b**) show a complete tear of the quadriceps tendon (*large arrow*). Note the degenerative changes of the tendon (*small arrow*) which indicates a weakened tendon

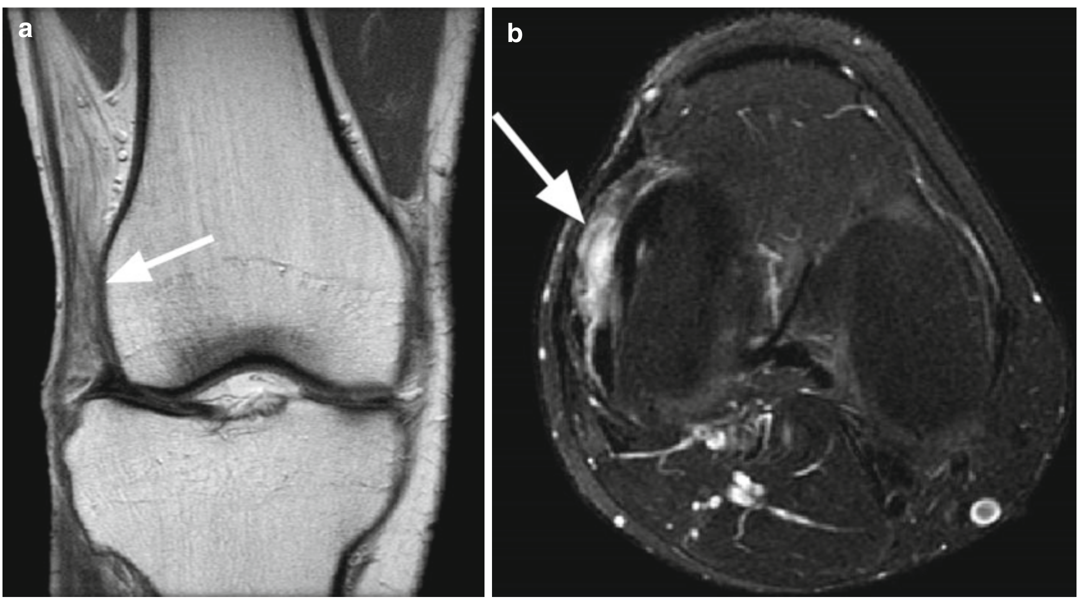

Fig. 9.22 Iliotibial band syndrome (iliotibial friction syndrome) in a 22 year old male. Coronal proton-density (PD) image (**a**) and axial proton-density (PD) fat-suppressed image (**b**) show a poorly defined soft tissue edema (*arrow*) in the fatty tissue between the iliotibial band and the femoral condyle

Fig. 9.23 Subtotal biceps tendon tear in a 31 year old male. Axial proton-density (PD) fat-suppressed image shows focal high-signal-intensity lesion which involves more than 50 % of the tendon diameter (*arrow*)

formation [47, 48]. On MR imaging, the cysts are well-delineated uni- or multilobulated lesions homogeneous hypointense on T1-weighted images and hyperintense on T2-weighted images. They may present internal septation and are located adjacent to the tendon.

9.3 MRI Impression

1. Anomalous muscle – description of insertion and position relative to neurovascular bundle
2. Muscle contusion or muscle tear – including the specific muscle or muscles, the extension of the lesion, and the grade (minor, moderate, or subtotal/complete tear)
3. Myositis ossificans – location and dimension
4. Intra- or peritendinous ganglion cyst – location and dimension

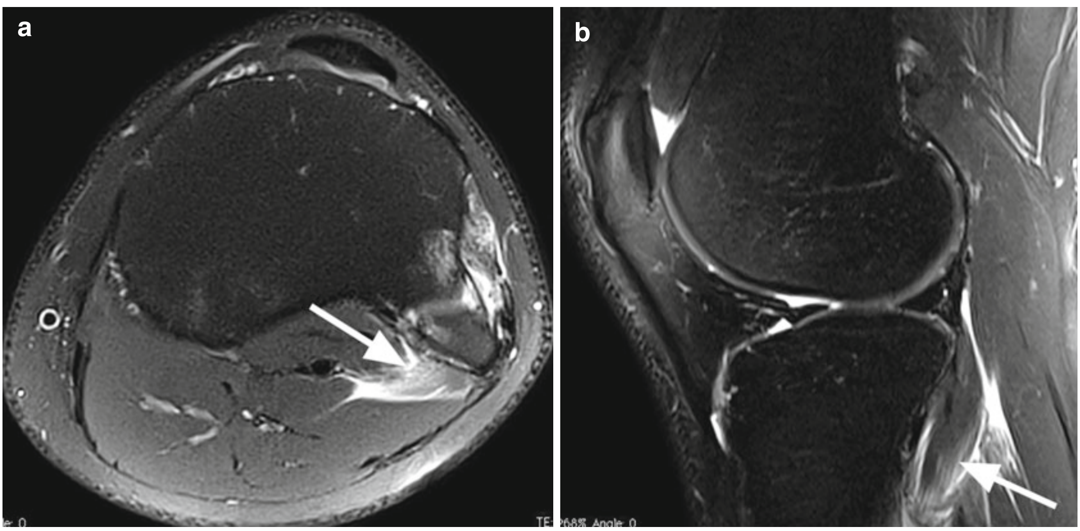

Fig. 9.24 Moderate partial tear of the musculotendinous junction of popliteus muscle in a 26 year old male. Axial proton-density (PD) fat-suppressed image (**a**), sagittal T2-weighted fat-suppressed image (**b**), and coronal proton-density (PD) fat-suppressed image (**c**) show diffuse edema involving more than a muscle fascicle but less than 50 % of the muscle thickness (*arrow*)

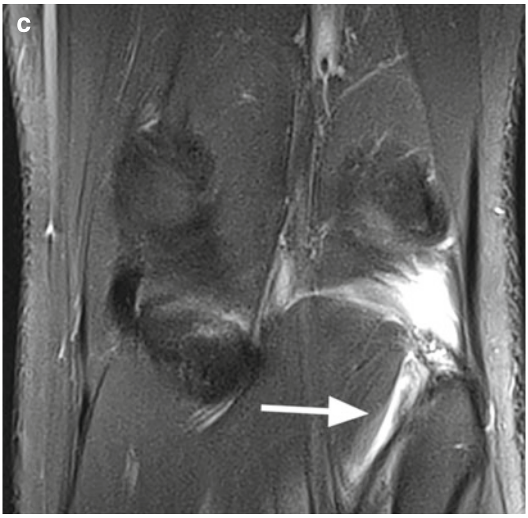

Fig. 9.24 (continued)

References

1. Waligora AC, Johanson NA, Hirsch BE. Clinical anatomy of the quadriceps femoris and extensor apparatus of the knee. Clin Orthop Relat Res. 2009;467(12): 3297–306.
2. Zeiss J, Saddemi SR, Ebraheim NA. MR imaging of the quadriceps tendon: normal layered configuration and its importance in cases of tendon rupture. AJR Am J Roentgenol. 1992;159(5):1031–4.
3. Fulkerson JP, Gossling HR. Anatomy of the knee joint lateral retinaculum. Clin Orthop Relat Res. 1980;153: 183–8.
4. Vieira EL, et al. An anatomic study of the iliotibial tract. Arthroscopy. 2007;23(3):269–74.
5. Munshi M, et al. MR imaging, MR arthrography, and specimen correlation of the posterolateral corner of the knee: an anatomic study. AJR Am J Roentgenol. 2003;180(4):1095–101.
6. Staubli HU, Birrer S. The popliteus tendon and its fascicles at the popliteal hiatus: gross anatomy and functional arthroscopic evaluation with and without anterior cruciate ligament deficiency. Arthroscopy. 1990;6(3):209–20.
7. Watanabe Y, et al. Functional anatomy of the posterolateral structures of the knee. Arthroscopy. 1993;9(1): 57–62.
8. Recondo JA, et al. Lateral stabilizing structures of the knee: functional anatomy and injuries assessed with MR imaging. Radiographics. 2000;20 Spec No:S91–102.
9. Bolog N, Hodler J. MR imaging of the posterolateral corner of the knee. Skeletal Radiol. 2007;36(8): 715–28.
10. Levien LJ. Popliteal artery entrapment syndrome. Semin Vasc Surg. 2003;16(3):223–31.
11. Macedo TA, et al. Popliteal artery entrapment syndrome: role of imaging in the diagnosis. AJR Am J Roentgenol. 2003;181(5):1259–65.
12. Kim HK, Laor T, Racadio JM. MR imaging assessment of the lateral head of the gastrocnemius muscle: prevalence of segmental anomalous origins in children and young adults. Pediatr Radiol. 2008;38(12):1300–5.
13. Tubbs RS, Salter EG, Oakes WJ. Dissection of a rare accessory muscle of the leg: the tensor fasciae suralis muscle. Clin Anat. 2006;19(6):571–2.
14. Sookur PA, et al. Accessory muscles: anatomy, symptoms, and radiologic evaluation. Radiographics. 2008; 28(2):481–99.
15. Beiner JM, Jokl P. Muscle contusion injuries: current treatment options. J Am Acad Orthop Surg. 2001;9(4): 227–37.
16. Kary JM. Diagnosis and management of quadriceps strains and contusions. Curr Rev Musculoskelet Med. 2010;3(1–4):26–31.
17. Ryan JB, et al. Quadriceps contusions. West Point update. Am J Sports Med. 1991;19(3):299–304.
18. Mueller-Wohlfahrt HW, et al. Terminology and classification of muscle injuries in sport: the Munich consensus statement. Br J Sports Med. 2013;47(6):342–50.
19. El-Khoury GY, et al. Imaging of muscle injuries. Skeletal Radiol. 1996;25(1):3–11.
20. Beiner JM, Jokl P. Muscle contusion injury and myositis ossificans traumatica. Clin Orthop Relat Res. 2002;403S:S110–S119.doi:10.1097/00003086-200210001-00013
21. Kransdorf MJ, Meis JM, Jelinek JS. Myositis ossificans: MR appearance with radiologic-pathologic correlation. AJR Am J Roentgenol. 1991;157(6):1243–8.
22. Malliaropoulos N, et al. Posterior thigh muscle injuries in elite track and field athletes. Am J Sports Med. 2010;38(9):1813–9.
23. Orchard J, Best TM, Verrall GM. Return to play following muscle strains. Clin J Sport Med. 2005;15(6): 436–41.
24. Sonin AH, et al. MR imaging appearance of the extensor mechanism of the knee: functional anatomy and injury patterns. Radiographics. 1995;15(2):367–82.
25. Bencardino JT, et al. Traumatic musculotendinous injuries of the knee: diagnosis with MR imaging. Radiographics. 2000;20 Spec No:S103–20.
26. Helfenstein Jr M, Kuromoto J. Anserine syndrome. Rev Bras Reumatol. 2010;50(3):313–27.
27. Chan KK, et al. Posteromedial tibial plateau injury including avulsion fracture of the semimembranous tendon insertion site: ancillary sign of anterior cruciate ligament tear at MR imaging. Radiology. 1999;211(3):754–8.
28. Menz MJ, Lucas GL. Magnetic resonance imaging of a rupture of the medial head of the gastrocnemius muscle. A case report. J Bone Joint Surg Am. 1991; 73(8):1260–2.
29. Helms CA, Fritz RC, Garvin GJ. Plantaris muscle injury: evaluation with MR imaging. Radiology. 1995;195(1):201–3.
30. Messier SP, et al. Etiology of iliotibial band friction syndrome in distance runners. Med Sci Sports Exerc. 1995;27(7):951–60.

31. Fredericson M, et al. Hip abductor weakness in distance runners with iliotibial band syndrome. Clin J Sport Med. 2000;10(3):169–75.
32. Ellis R, Hing W, Reid D. Iliotibial band friction syndrome–a systematic review. Man Ther. 2007;12(3): 200–8.
33. Lavine R. Iliotibial band friction syndrome. Curr Rev Musculoskelet Med. 2010;3(1–4):18–22.
34. Tenforde AS, et al. Overuse injuries in high school runners: lifetime prevalence and prevention strategies. PM R. 2011;3(2):125–31; quiz 131.
35. Devan MR, et al. A prospective study of overuse knee injuries among female athletes with muscle imbalances and structural abnormalities. J Athl Train. 2004;39(3):263–7.
36. Rumball JS, et al. Rowing injuries. Sports Med. 2005;35(6):537–55.
37. Strauss EJ, et al. Iliotibial band syndrome: evaluation and management. J Am Acad Orthop Surg. 2011; 19(12):728–36.
38. Fairclough J, et al. The functional anatomy of the iliotibial band during flexion and extension of the knee: implications for understanding iliotibial band syndrome. J Anat. 2006;208(3):309–16.
39. Muhle C, et al. Iliotibial band friction syndrome: MR imaging findings in 16 patients and MR arthrographic study of six cadaveric knees. Radiology. 1999;212(1): 103–10.
40. Martens M, Libbrecht P, Burssens A. Surgical treatment of the iliotibial band friction syndrome. Am J Sports Med. 1989;17(5):651–4.
41. Becker EH, Watson JD, Dreese JC. Investigation of multiligamentous knee injury patterns with associated injuries presenting at a level I trauma center. J Orthop Trauma. 2013;27(4):226–31.
42. Brown TR, et al. Diagnosis of popliteus injuries with MR imaging. Skeletal Radiol. 1995;24(7):511–4.
43. Gottsegen CJ, et al. Avulsion fractures of the knee: imaging findings and clinical significance. Radiographics. 2008;28(6):1755–70.
44. Vayvada H, et al. Giant ganglion cyst of the quadriceps femoris tendon. Knee Surg Sports Traumatol Arthrosc. 2003;11(4):260–2.
45. Kim SK, et al. Intratendinous ganglion cyst of the semimembranosus tendon. Br J Radiol. 2010;83(988): e79–82.
46. Jose J, O'Donnell K, Lesniak B. Symptomatic intratendinous ganglion cyst of the patellar tendon. Orthopedics. 2011;34(2):135.
47. Robertson DE. Cystic degeneration of the peroneus brevis tendon. J Bone Joint Surg Br. 1959;41-B(2): 362–4.
48. Pedrinelli A, et al. Anterior cruciate ligament ganglion: case report. Sao Paulo Med J. 2002;120(6): 195–7.