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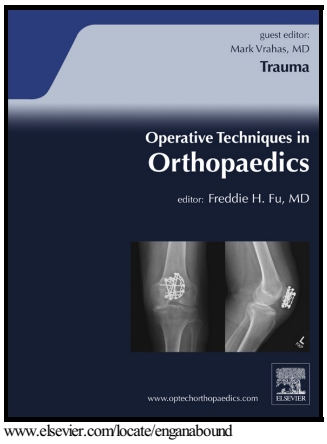

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Title

Layer-by-Layer Anatomy of the Anterolateral Complex of the Knee

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Abstract

Injuries to the anterior cruciate ligament (ACL) can be associated with anterolateral capsular injuries. Recently, these capsular tears have been suggested to play an important role in rotatory knee instability. A critical review of the anterolateral complex of the knee is necessary to clarify nomenclatures of same structures and the complex anatomy of anterolateral side of the knee. In addition to the lateral collateral ligament and the arcuate complex, the iliotibial band (ITB) is an important lateral structure. It consists of different layers; the superficial, middle, deep and capsulo-osseous layer. Further, in a subset of patients, a capsular thickening, i.e. the mid-third capsular ligament can be observed. Biomechanically, the functional unit of the ITB with its deeper layers between the firm attachment on the distal lateral femoral metaphysis (Kaplan fibers) and Gerdy´s tubercle was shown to contribute the most to resist internal tibial rotation. Therefore, the ITB and its deeper layers as well as the mid-third capsular ligament should be referred to collectively as the anterolateral complex.

Keywords: Knee, anterolateral, iliotibial band, capsulo-osseous layer, capsule, anatomy

Introduction

Anterior cruciate ligament (ACL) injury results in an anterolateral rotatory instability of the knee joint. In order to restore normal knee kinematics, surgeons have to address this coupled anterior translation and internal rotation of the tibia relative to the femur. However, associated injuries (i.e. meniscus tears), bone morphology and anterolateral capsular injuries as well as non-anatomic ACL reconstruction can lead to a persistent pivot shift phenomenon postoperatively.[1-9] Recently, a distinct ligamentous structure has been described on the lateral aspect of the knee.[10, 11] This ligament was suggested to play an important role in restraint of rotatory instability and pivot shift.[6, 7, 12] In recent years, focus has been placed on the anatomy, histology, function, and structural properties of this lateral structure, termed the anterolateral ligament.[6, 7, 10-14] However, conflicting findings may result in confusion amongst orthopaedic surgeons. Reasons for these inconsistent reports may include different anatomic terminology[10, 11, 15, 16], dissection techniques as well as specimen fixation (embalmed[10, 17-19] versus fresh-frozen[11, 20, 21]) methods. Furthermore, these structures have been described in the classic literature, but may need to be reviewed in the context of the anterolateral complex.[15, 16] Furthermore, to better understand the complex anatomy of the anterolateral aspect of the knee, one should be familiar with the development and evolution of the knee joint.

Development and evolution of the knee joint

The thigh and lower leg are already separated during the earliest embryonic stages, while the tibia and fibula are developing from the same sheet of blastema. At this stage, both fibula and tibia are in contact with the femur. In embryos 50 days of age, the tibia and fibula can be appreciated as two different structures, with the tibia being the only bone precursor articulating with the femur. In the following stages, the fibula is further growing apart from the femur.[22-25] At nine to 10 weeks of gestational age, the shape of the future bones of the lower limb is similar as in adults.[26, 27] The fibrous joint capsule enveloping the tibiofemoral joint cavity begins to evolve by 11 weeks from dense collagen fibers in the posterior part of the knee[27], while the superficial layer is encompassing the distalized fibula.[22-25] At 14 weeks, the structure of the lateral collateral ligament (LCL) is close to that of an adult knee, similar to the well-defined and demarked iliotibial band (ITB).[27, 28] After 14 weeks, knee joint development can be considered as complete.[29]

The layer anatomy of the anterolateral complex

Unlike the medial part of the knee, which consists of three distinct layers as described by Warren and Marshall[30] the lateral side of the knee is more complex. As described above, the distalization of the fibula during early development of the knee joint explains the formation of a new capsular layer surrounding only the tibiofemoral joint.[22-25]

Seebacher et al. first described the layer by layer anatomy on the lateral aspect of the knee.[22] Layer 1 consists of the fascia including the iliotibial band anterolaterally and the fascia of the biceps femoris posterolaterally. Layer 2 is defined by the retinacula and the aponeurosis of the quadriceps and the lateral patellofemoral ligaments. Thus, Layer 2 is incomplete in its posterior part, while it fuses with Layer 1 in its anterior most portion close to the patella and patellar tendon.[15, 22] The third layer consists of the joint capsule. The joint capsule has two laminae in the area of the LCL and posterior to the ITB; the superficial lamina (original joint capsule embryologically), which surrounds the lateral collateral ligament (LCL), and the deep lamina lying medial to the LCL. Loose connective tissue and the inferior genicular vessels are between the two laminae of the joint capsule. Anterior to the LCL the two layers fuse.[22]

Interestingly, the ITB itself has been described as a structure with different layers[15, 16, 20, 22, 31, 32]; it is the superficial ITB, the deep, middle and capsule-osseous layer.[15] These layers of the ITB connect Layer 1 with Layer 3 as well as with the distal femur in the proximal and posterior part of the lateral aspect of the knee.[15]

Superficial Iliotibial Band

The superficial ITB (Fig. 1) inserts widely with its most prominent middle fibers to Gerdy´s tubercle and around it.[15, 20, 32, 33] Its anterior part runs in a curved fashion to the lateral aspect of the patella and patellar tendon (so called iliopatellar band).[15, 20, 32, 33] The most posterior fibers of the superficial ITB reinforce the fascia of the biceps femoris muscle (Fig. 1).[20, 31-34] Proximal to the femoral condyle, the posterior superficial ITB inserts into the linea aspera of the femur via the intermuscular septum (Fig. 2).[31, 33]

Middle and deep layer of the ITB

The middle layer of the ITB is characterized by a different fiber alignment. While the fibers of the superficial ITB run in a vertical direction from proximal to distal, the middle layer fibers of the ITB are aligned obliquely from lateral proximal to medial distal.[15] However, the superficial and middle layer of the ITB can only be separated by sharp dissection.[15]

The deep layer of the ITB lies in the posterior most part of the superficial ITB and originates distal to the termination of the lateral intermuscular septum.[15, 20] This layer extends distally deep to the superficial ITB and blends with it distal to the femoral epicondyle, reinforcing the superficial ITB.[15, 20] The so-called Kaplan fibers (Fig. 2) are part of the deep layer of the ITB. The Kaplan fibers represent a distinct and firm supraepicondylar insertion of the ITB distal to the intermuscular septum.[16, 20, 33] Lobenhoffer et al.[16] found in their dissection study different insertion patterns of these transverse fiber bundles, which were present in 93% of the cases. In 70% of their dissections, these fibers were found to insert proximal and anterior to the lateral femoral epicondyle. In 73% an additional insertion was observed on the dorsolateral femoral

shaft where the intermuscular septum terminates.[16] It should be noted, that the Kaplan fibers are in close proximity to the branches of the superior genicular artery.[16] In fact, in patients with a rotatory knee trauma, hemorrhage in this area is frequently evident on magnetic resonance imaging (Fig. 3). The part of the superficial and deep ITB between the Kaplan fibers and the distal insertion on the proximal tibia form a functional unit that may contribute to rotatory knee stability.[16, 32] Hassler and Jakob observed a tightening of this functional unit with the knee in flexion.[32] Lobenhoffer et al. found an increase of up to 18% in the distance between the femoral and tibial insertions of this functional unit once the knee becomes flexed. The highest distance was observed when the knee was flexed of about 60°.[16] These findings have been recently confirmed with a robotic study demonstrating that both the superficial and deep ITB contribute more than 70% in resisting internal tibial rotation at 60° and 90° of knee flexion in an anterior cruciate ligament (ACL) intact and deficient knee.[14] In that study, the so-called capsulo-osseous layer of the ITB was considered as deep ITB.[14] However, several articles have described this layer to be separate from the superficial and deep ITB.[15-17, 20]

The capsulo-osseous layer of the ITB

First described by Terry et al.[15], the capsulo-osseous layer of the ITB (Fig. 2) is in its proximal part contiguous with the fascia of the plantaris and lateral gastrocnemius muscles and inserts distally just posterior and slightly distal to Gerdy´s tubercle.[15, 16] Additionally, some proximal fibers insert in the area of the lateral femoral epicondyle.[16] The capsulo-osseous layer runs in the posterior aspect of the superficial ITB, merging with it distally.[16] To better understand the topography of the capsulo-osseous layer, it should be mentioned that the muscle fibers of the short head of the biceps femoris muscle as well as its fascia insert to it laterally (so-called biceps-capsulo-osseous iliotibial tract confluence according to Terry et al.).[15, 34]

The anterolateral capsule of the knee

As mentioned above, the lateral joint capsule has a complex architecture with the superficial and deep lamina being confluent anterior to the LCL.[22] Hughston et al. distinguished in his descriptions between the anterior, middle and posterior thirds of the lateral knee ligaments including the capsular ligaments.[35] The anterior third with its thin anterior capsular ligament refers to the region between the patella and patellar tendon anteriorly and the anterior border of the superficial ITB posteriorly. The middle third is in the area of the superficial ITB and the mid-third capsular ligament deep to it. This mid-third capsular ligament has its origin on the lateral femoral epicondyle and distally at the tibial joint margin. The mid-third capsular ligament attaches to the meniscus and forms therefore the meniscotibial and meniscofemoral ligament.[36] The meniscotibial and meniscofemoral portion of this capsular thickening have also been described as the coronary ligament, formed by the deep lamina of the joint capsule.[22] The posterior third of the lateral ligaments composed of the arcuate complex with the LCL, the arcuate ligament and the popliteus tendon.[35]

Description of the anterolateral ligament

Recently, the so-called anterolateral ligament has been a topic of an ongoing scientific debate.[10] Different authors using the same nomenclature described its presence, morphology and insertions with conflicting findings.[10, 11, 17-21, 37] The reasons for the diverging reports arise from the complexity of the lateral anatomy, fixation methods of the dissected knees, as well as different dissection protocols. In 1950 the British anatomist R.J. Last described the lateral capsule as the following: “In truth, there is at this part of the capsule such a complexity of fibers running in many directions that, by artful dissection, almost any pattern desired by the dissector could be made!”[38] Further, different nomenclature for the same structures contributed to additional confusion. For example, Lobenhoffer et al.[16], described the capsulo-osseous layer according to Terry et al.[15] as the retrograde fiber tract of the ITB, while Vieira et al.[20] named this structure both the anterolateral ligament and the capsulo-osseous layer.

In the study by Dodds et al. on fresh-frozen cadaveric knees, the authors describe the anterolateral ligament as an extracapsular structure passing obliquely over the LCL without any attachments to the lateral meniscus. The femoral attachment was found to be far posterior on the lateral femoral condyle without any distinct area of bony insertion but adherence to the capsule. The tibial insertion has been described posteriorly to Gerdy´s tubercle.[21] Another study pointed out that the biceps femoris has to be removed in order to properly identify the posterior fibers of the anterolateral ligament.[19] They found their anterolateral ligament to be similar as the description of Dodds et al.. However, a distinct femoral bony insertion on the lateral femoral epicondyle or slightly proximal and posterior to it was described.[19] Stijak et al.[17] found these fibers to be a posterior continuation of the superficial ITB and concluded that this structure might be the same as named by Terry et al.[15] as the capsulo-osseous layer.[17] Considering the anatomic descriptions of the anterolateral ligament in the articles mentioned in this paragraph as well as by Paul Segond in 1978[39], the authors are most likely referring to the capsulo-osseous layer of the ITB.

Other descriptions of the anterolateral ligament[11, 17, 18, 37] consider it a capsular ligament (Layer 3 according to Seebacher et al.[22]) running obliquely from an area on the lateral femoral epicondyle to the proximal tibia posterior to Gerdy´s tubercle. However, another study found, that this ligament can be delineated from the joint capsule.[10] When interpreting these findings, it must be mentioned that most of these studies used embalmed specimens[10, 17-19], in which a careful layer-by-layer dissection becomes difficult. It is likely that the authors could not properly distinguish between the mid-third capsular ligament and the distal part of the capsulo-osseous layer of the ITB. This is also evidenced by the fact that the described extra-articular anterolateral ligament was found to have a firm attachment to the lateral meniscus.[10] After reviewing the

literature of the anterolateral aspect of the knee, the likely conclusion is that the recently described anterolateral ligament refers either to the capsulo-osseous layer of the ITB[19, 21] or to the mid-third capsular ligament[10, 17, 18, 37].

Conclusion

The complex anatomy of the anterolateral aspect of the knee can be divided into three general layers. The central part of this anatomy is the iliotibial band with its superficial, middle, deep, and capsulo-osseous layer. Further, in a subset of specimens a capsular thickening (mid-third capsular ligament) can be observed. The ITB and its deeper layers, as well as the mid-third capsular ligament, should be referred to collectively as the anterolateral capsular complex of the knee.

Figures

Figure 1

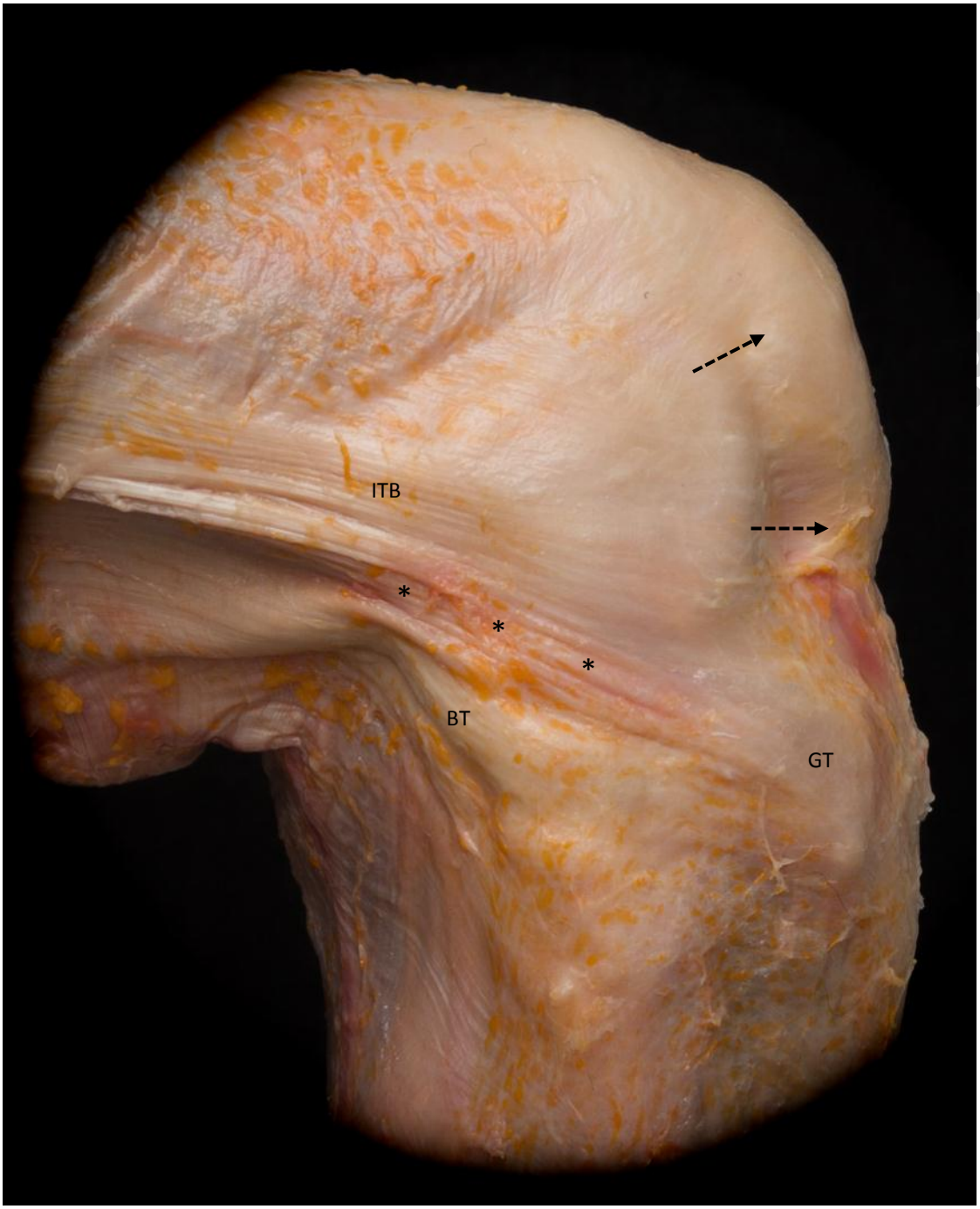

Fig. 1: Layer 1 is characterized by fascia cruris including the iliotibial band (ITB) and the fascia of the biceps muscle and tendon (BT). The superficial ITB inserts on Gerdy´s tubercle (GT). At 90° of knee flexion the posterior fibers of the superficial ITB become folded (black asterisks). The dotted arrows are highlighting the iliopatellar fibers of the ITB.

Figure 2:

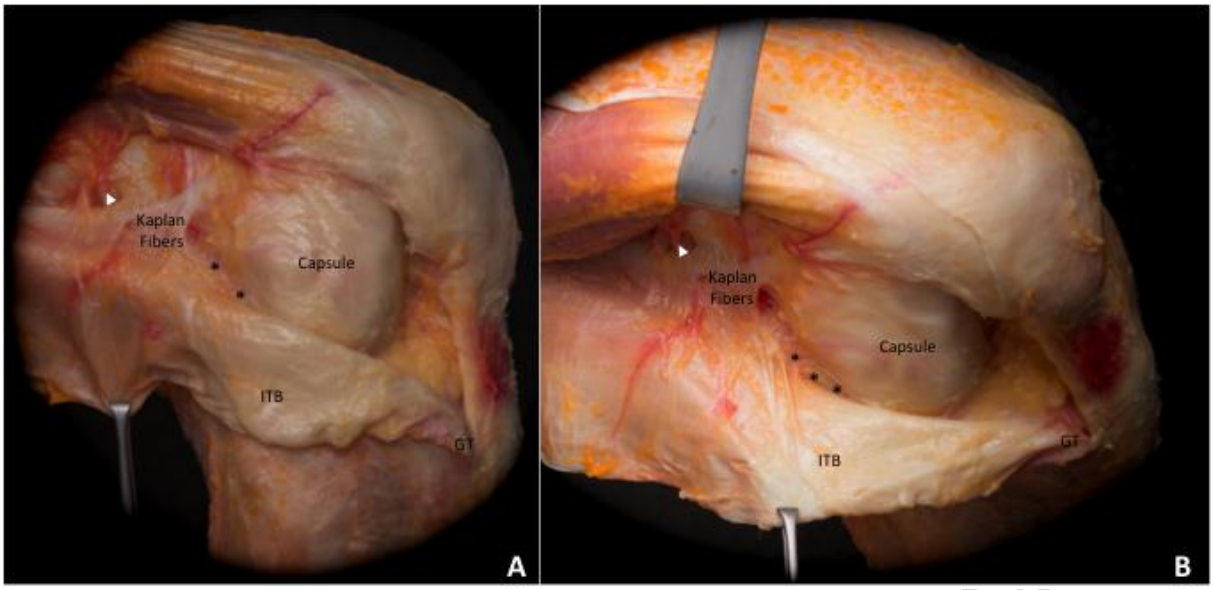

Fig. 2: Posterior reflection of the ITB reveals the deep layers. The ITB has a firm attachment on the distal femoral metaphysis (Kaplan fibers). The superior genicular vessels are in close proximity to these fibers (white arrowhead). The black asterisks mark the capsulo-osseous layer of the ITB (A, B), which blends with it in its distal part (B).

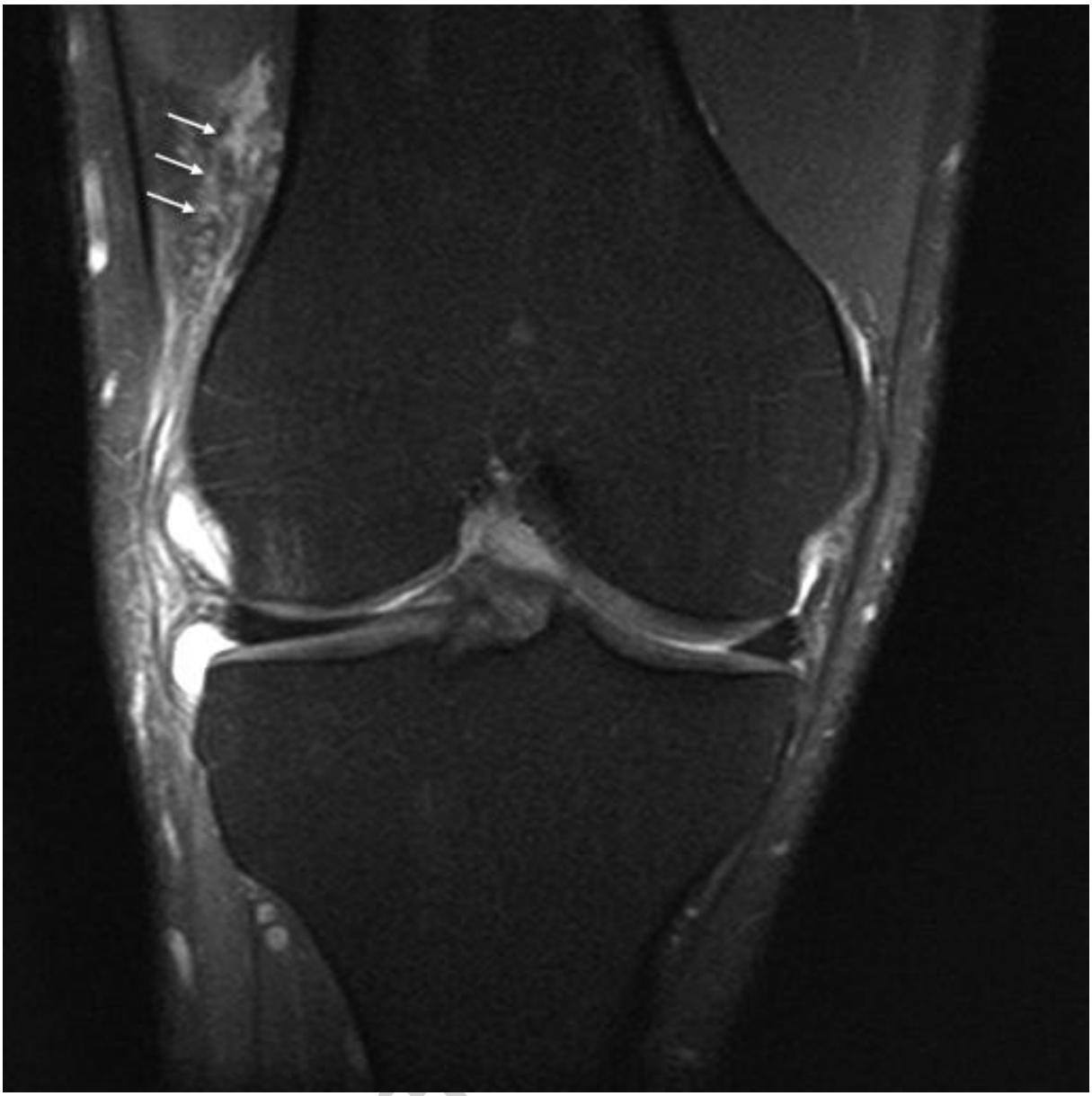

Fig. 3: T2 weighted MRI of an anterior cruciate ligament injured patient. The white arrows indicate the hemorrhage deep to the superficial ITB in the area where the Kaplan fibers insert.

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