Pictorial essay

Cite as: Tamborrini G, Micheroli R, Ricci V, Becciolini M, Garcia-Pompermayer M, Gonzalo ASB, Toranelli M, Margenfeld F, Müller-Gerbl M: Enhancing knee imaging via histology and anatomy-driven high-resolution musculoskeletal ultrasound. J Ultrason 2025; 25: 8. doi: 10.15557/JoU.2025.0008.

Submitted: 03.11.2024
Accepted: 27.01.2025
Published: 27.03.2025

Enhancing knee imaging via histology and anatomy-driven high-resolution musculoskeletal ultrasound

Giorgio Tamborrini*[1,2], Raphael Micheroli*[1,3], Vincenzo Ricci[4], Marco Becciolini[5,6], Mario Garcia-Pompermayer[7], Andres Serrano Belmar Gonzalo[8], Mireille Toranelli[9], Felix Margenfeld#[9], Magdalena Müller-Gerbl#[9]

[1] *Ultrasound, UZR – Swiss Ultrasound Center, Institute of Rheumatology, Switzerland*
[2] *Clinic for Rheumatology, University Hospital of Basel, Switzerland*
[3] *Department of Rheumatology, University Hospital Zürich, Switzerland*
[4] *Physical and Rehabilitation Medicine Unit, Luigi Sacco University Hospital, ASST Fatebenefratelli-Sacco, Italy*
[5] *Ultrasound, Misericordia di Pistoia, Italy*
[6] *Scuola Siumb di Ecografia Muscoloscheletrica, Ultrasound, Italy*
[7] *Hospital San Jose, TecSalud, Tecnologico de Monterre, Rheumatology, Mexico*
[8] *Clínica Alemana, Department of Radiology, Chile*
[9] *Institute of Anatomy, Department of Biomedicine, Musculoskeletal Research, University of Basel, Switzerland*

** First author; # Last author*

Corresponding author: Giorgio Tamborrini; e-mail: msk_ultrasound@pm.me

DOI: 10.15557/JoU.2025.0008

Keywords
musculoskeletal; ultrasound; histology; knee; sonography

Abstract

Purpose: To provide an overview of the normal anatomy of the knee using high-resolution ultrasonography. **Materials and methods:** Normal ultrasound images were obtained from a healthy subject, and corresponding images of human anatomy and histology were acquired from body donors. **Results:** Several high-resolution ultrasound, anatomical, and histological images were created to illustrate and comprehensively describe the basic standard scans in compliance with international standards. This atlas summarizes a selection of typical normal findings. **Conclusions:** This overview explains the normal anatomy of the knee as seen by ultrasonography. High-resolution knee musculoskeletal ultrasonography aims to provide an accurate structural evaluation, which requires comprehensive knowledge of sonoanatomy. When used appropriately, contemporary high-resolution musculoskeletal ultrasonography enhances knee imaging by connecting anatomical cross-sections and intricate histology to specific anatomical features.

Introduction

Recent advancements in ultrasound hardware and software have significantly expanded its use in evaluating the musculoskeletal system[1]. Due to its excellent spatial resolution and dynamic capabilities, ultrasound can be regarded as the first-line imaging method in various clinical circumstances for assessing knee diseases. When evaluating most intra-articular structures, magnetic resonance imaging (MRI) performs better than ultrasound[2]. Nonetheless, ultrasound remains a precise, accessible, and cost-effective diagnostic tool for a variety of conditions involving tendons, blood vessels, nerves, and other periarticular structures.

While traditional anatomical descriptions focus on isolated structures, modern ultrasound examination requires an understanding of functional anatomical complexes. This approach bridges the gap between static anatomy and dynamic clinical assessment, which is particularly crucial in complex regions such as the posteromedial and posterolateral corners of the knee. This review uniquely emphasizes the integration of anatomical knowledge with practical ultrasound examination techniques, offering a framework for both novice and experienced sonographers.

Material and methods

Standard ultrasound images were obtained from a healthy subject (acquired mainly by the first author of this pictorial essay), while images of the human anatomy and histology were acquired from body donors. To produce whole-joint histological slices, three knee joints were embedded in methyl methacrylate (MME) as suggested by Hauser *et al.*[3]. Transverse, sagittal, and frontal sections were cut using a diamond circular saw with a blade thickness of 400 µm. The resulting 1200 µm thick slices were fixed on white, translucent object holders for further processing. The slides were then ground to a maximum thickness of 250 µm and polished. Each section surface was stained with toluidine blue epoxy staining (penetration thickness: 3 µm) to highlight basophilic structures, producing varying shades of blue, with calcified cartilage displaying the darkest shade. The resulting histological slices were documented for inspection (IMS Client software, 20.5: 1 Zoom and FusionOptics Technology Leica M205C; Canon EOS 40D). Ethical approval was not required. The Declaration of Helsinki was fulfilled.

General ultrasound aspects

We recommend using linear probes with frequencies ranging from 10 to 24 MHz to examine superficial structures of the knee (e.g. entheses or superficial nerves such as the common peroneal nerve and its divisions). For assessing deeper regions, a lower frequency range, between 8 and 12 MHz, is more appropriate[4]. The ultrasound device used for this Review was a LOGIQ E10 system from GE with R3 software. The probes used were ML6-15-D, ML4-20, L8-18i-D and L6-24-D, with frequencies ranging from 8 MHz to 24 MHz, depending on the structure being assessed. The patient lies in a supine position for examining the anterior, medial, and lateral structures of the knee. Panoramic scanning is helpful to visualize larger structures in greater detail. For the static and dynamic examinations of the anterior, medial, and lateral structures of the knee, different positions are recommended: full extension, mild flexion (20–30 degrees), and maximal flexion. The medial and lateral regions are functionally assessed with varus and valgus stress. Lastly, the posterior knee is evaluated while the patient is prone or standing[5].

The following Anatomical-Radiological Correlation Principles were applied:

- structure identification requires an understanding of both the 2D ultrasound appearance and 3D anatomical relationships;
- probe positioning should follow anatomical planes while accounting for structure orientation;
- dynamic examination reveals functional relationships between anatomical structures;
- anisotropy can be used advantageously to confirm structure identity;
- complex regions require systematic scanning approaches based on layered anatomy.

Anterior knee region

The systematic examination of the anterior knee combines efficient scanning techniques with a comprehensive anatomical assessment. The process begins with the knee extended, then progresses to 20–30 degree flexion[6] (Tab. 1), with a pillow placed under the knee for support. Following best practice, the examination starts with a transverse sonogram in the mid-thigh area, moving the ultrasound probe downwards using the elevator technique. The femur serves as an osseous landmark for adjusting scanning depth and orientation.

The second phase involves a longitudinal examination, where the probe moves systematically from proximal to distal, following the quadriceps muscle, the articularis genu muscle, its myotendinous junction, and finally, the quadriceps tendon with its insertion at the patella[7] (Fig. 1). Proper transducer angulation is essential to avoid anisotropy; the probe must be tilted distally while maintaining its axis parallel to the tendon. This technical consideration is particularly important during extension views to optimize visualization.

Tab. 1. Anterior knee region: patient position, scanning technique, and assessed structures

Anterior knee region: • Knee anterior transverse and longitudinal position: supine position, hip joint in neutral position, knee joint in flexion (knee approx. 20–30° flexion) and extended • Static and dynamic analysis of structures • Osseous landmarks: femur, patella, tibia, fibula
Assessed structures: • Cartilage of the femoral trochlea and articular facet of the patella (position: maximally flexed knee) • Distal femoral metaphysis and femoral trochlea (position: maximally flexed knee) • Upper pole of the patella: quadriceps tendon insertion • Myotendinous junction of the quadriceps muscle • Quadriceps tendon (superficial layer: tendon of the rectus femoris muscle; intermediate layer: tendon of the vastus lateralis and medialis muscles; deep layer: tendon of the vastus intermedius muscle) • Articularis genu muscle • Suprapatellar and prefemoral fat pad • Suprapatellar recess • Medial and lateral recesses • Medial and lateral patellar retinaculum • Medial and lateral parapatellar recesses • Infrapatellar recesses (suprahoffatic and infrahoffatic) • Prepatellar bursa • Patellar ligament/tendon • Hoffa's fat pad • Superficial and deep infrapatellar bursa • Tibial tuberosity • Femoral condyle • Anterior cruciate ligament (position: maximally flexed knee)

The quadriceps tendon typically displays three distinct layers, best appreciated in the longitudinal plane:

- superficial part: rectus femoris;
- intermediate part: vastus lateralis and medialis;
- deep part: vastus intermedius.

Differentiating between the intermediate and deep tendon laminae can be challenging due to varying quantities of fat, but the superficial tendon remains consistently visible. Tracing the aponeurosis from proximal to distal aids in distinguishing each component. Anatomical variations exist, with the possibility of encountering up to eight accessory heads. The articularis genus, a multi-layered muscle originating from the anterior surface of the distal third of the femur, attaches to the suprapatellar recess and joint capsule. Its intricate relationship with the vastus intermedius and vastus medialis suggests it likely functions as part of an integrated unit rather than independently[8].

The suprapatellar region reveals several important structures. The suprapatellar hyperechoic fat pad lies deep to the distal third of the quadriceps tendon and superior to the upper pole of the patella, displaying a characteristic triangular form in the longitudinal view. The prefemoral fat pad appears in depth, superficial to the femur.

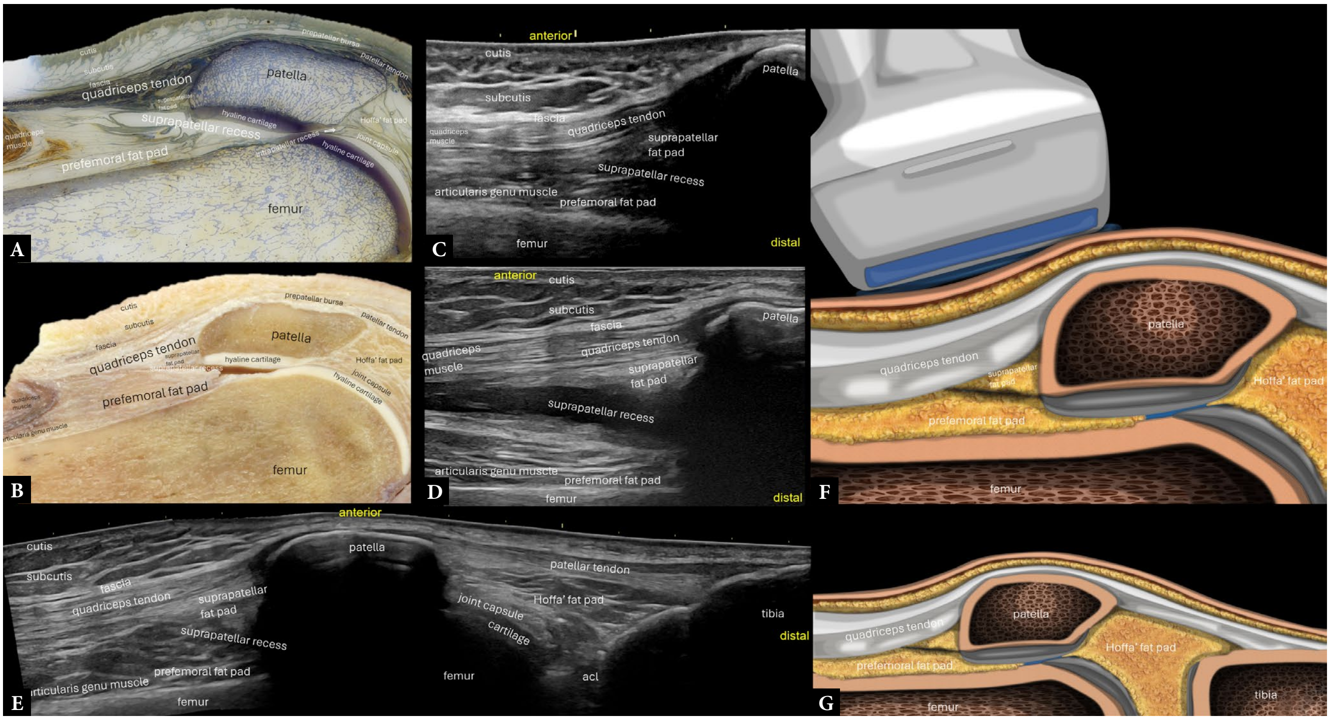

Fig. 1. *Anterior knee, suprapatellar region. Histological (***A***), anatomical (***B***), and corresponding ultrasound images (***C–E***). Illustrations with probe position in suprapatellar longitudinal (***F–G***) In C, longitudinal sonogram of the distal part of the relaxed quadriceps tendon.* **D.** *Longitudinal sonogram of the distal part of the quadriceps tendon, with the knee in mild flexion. The suprapatellar recess is distended by anechoic fluid in this case.* **E.** *Sagittal extended field of view of the anterior aspect of the knee. acl – anterior cruciate ligament*

Dynamic assessment allows evaluation of the interaction between these fat bodies during extension and flexion. Between them lies the suprapatellar recess, containing anechoic fluid that becomes more apparent when the joint is distended (Fig. 2). Additional fluid typically enters the suprapatellar recess from the femorotibial joint during quadriceps muscle tension, such as when lifting the extended leg. The prefemoral fat pad may show focal bulging in the inferolateral region of the suprapatellar recess – a finding that should not be mistaken for synovial proliferation or lipoma arborescens.

Examination of the quadriceps tendon insertion at the patella's upper pole requires a high-frequency transducer. This common enthesis shows characteristic changes in the tendon's fibrillar pattern, transitioning to a hypoechoic zone before insertion as the tendon develops into fibrocartilage. Individual quadriceps tendon fibers extend over the patella, communicating with the patellar tendon. Maximum knee flexion allows visualization of the femoral condyles' anechoic hyaline cartilage in both transverse and longitudinal planes.

Patellar examination proceeds both longitudinally and transversely, assessing the cortical bone and entheses at the quadriceps tendon insertion and patellar tendon origin. Normal findings include minimal cortical interruptions corresponding to nutritive vessel entrances, and variants such as bipartite patella should be noted. Manual internal tilting of the patella enables reliable visualization of the medial articular facet and retropatellar cartilage, though imaging the lateral facet and cartilage proves more challenging due to their frequent involvement in osteoarthritis and chondromalacia (Fig. 3). With the knee extended and relaxed, manual subluxation allows evaluation of the hyaline cartilage, though this is more complex medially. A generous application of ultrasound gel, without probe

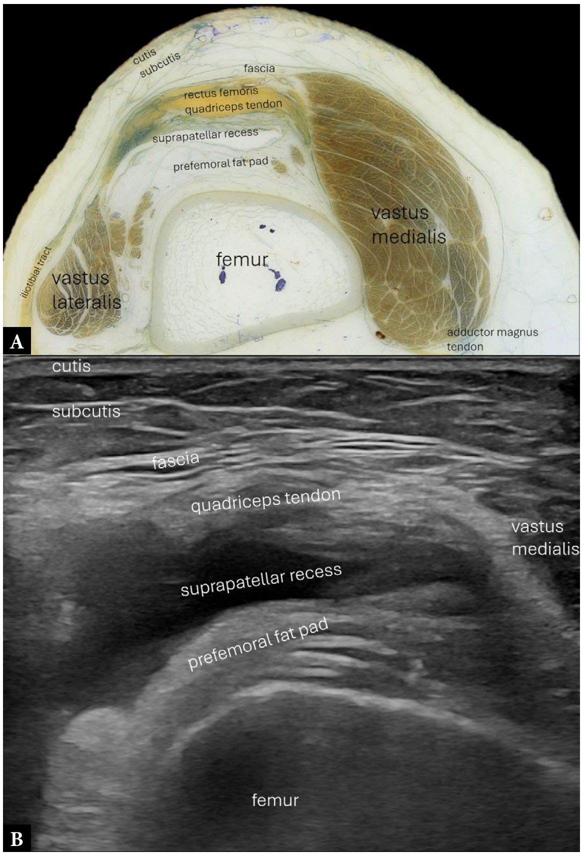

Fig. 2. *Anterior knee, suprapatellar region. Histological (***A***) and anterior transverse sonograms (***B***). In* **B***, a patient with moderate joint effusion is seen*

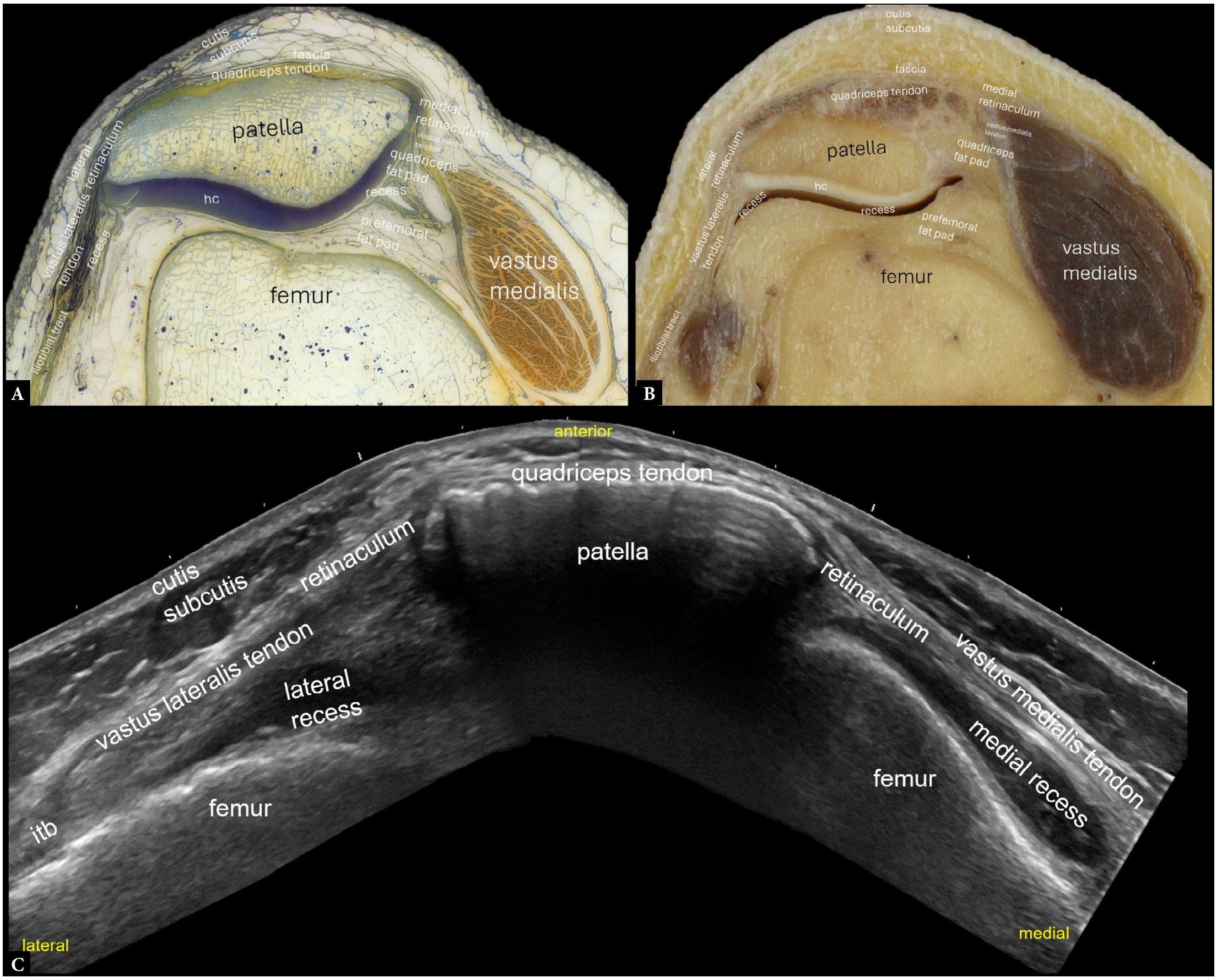

Fig. 3. *Anterior knee, patellar region. Transverse histological (***A***) and anatomical (***B***) sections.* **C.** *Extended field of view axial sonogram. Itb – iliotibial band; hc – hyaline cartilage*

pressure, reveals the prepatellar bursa, typically located subcutaneously from the middle to distal third of the patella with possible distal extension[9]. In some cases, the synovial membrane may contain minimal anechoic fluid.

Transverse scanning at the patellar level involves medial and lateral probe movements, assessing the vastus lateralis or medialis tendons, along with their respective patellar retinacula (Fig. 4). Compression of either the medial or lateral recess may trigger fluid movement to the opposite recess. The medial/lateral parapatellar recess presents a characteristic V-shape due to the triangular fat pad beneath the patellar retinaculum[10].

The examination of the infrapatellar region (Fig. 5) requires systematic evaluation of several distinct anatomical layers. The superficial infrapatellar bursa, positioned between the patellar ligament insertion at the tibial tuberosity and the subcutaneous fat[11], typically shows no detectable fluid under normal conditions. In contrast, the deep infrapatellar bursa, located between the tibial insertion of the patellar ligament and the anterior portion of the intracapsular Hoffa's fat pad, commonly demonstrates some fluid during maximum knee flexion – a normal, non-pathological finding.

The evaluation of the patellar tendon combines both dynamic and static assessment techniques. This crucial structure, connecting the patella to the tibial tuberosity, requires examination in both relaxed and tensed states to detect potential structural changes such as thickening, thinning, or disruption, which might suggest indicate pathology[12]. The distal portion characteristically displays slightly greater thickness. Deep to these structures, the distal femoral condyle can be visualized both longitudinally and transversely.

A comprehensive assessment of deeper structures requires technical adjustments. Using lower frequencies allows for an in-depth evaluation of the entire Hoffa's fat pad, synovial membrane, and femorotibial joint capsule, particularly where it interfaces with the femoral condyles' cartilage (Fig. 6). Dynamic assessment proves especially valuable for evaluating the Hoffa's fat pad, potentially revealing extrusion or protrusion of fat tissue through the medial/lateral retinaculum[13].

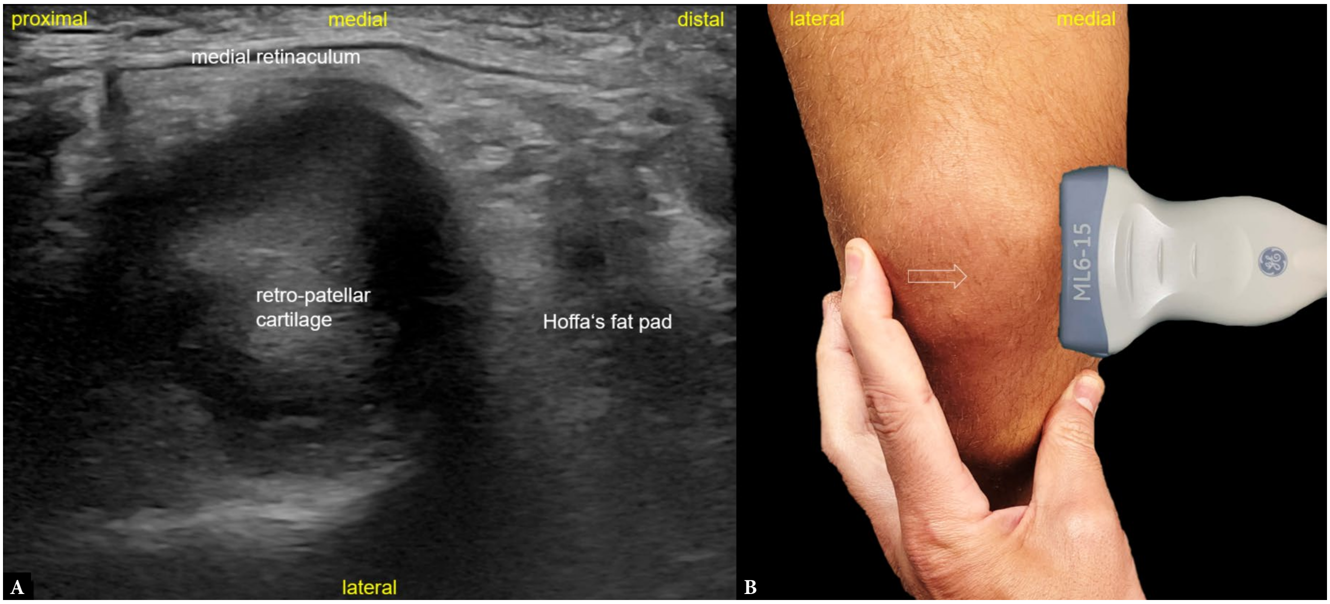

Fig. 4. *Anterior knee, retropatellar region.* **A.** *Longitudinal sonogram of the retro-patellar cartilage. The probe is placed medial to the patella. To obtain this image, the examiner must tilt and move the patella internally, as shown in* **B** *(void arrow)*

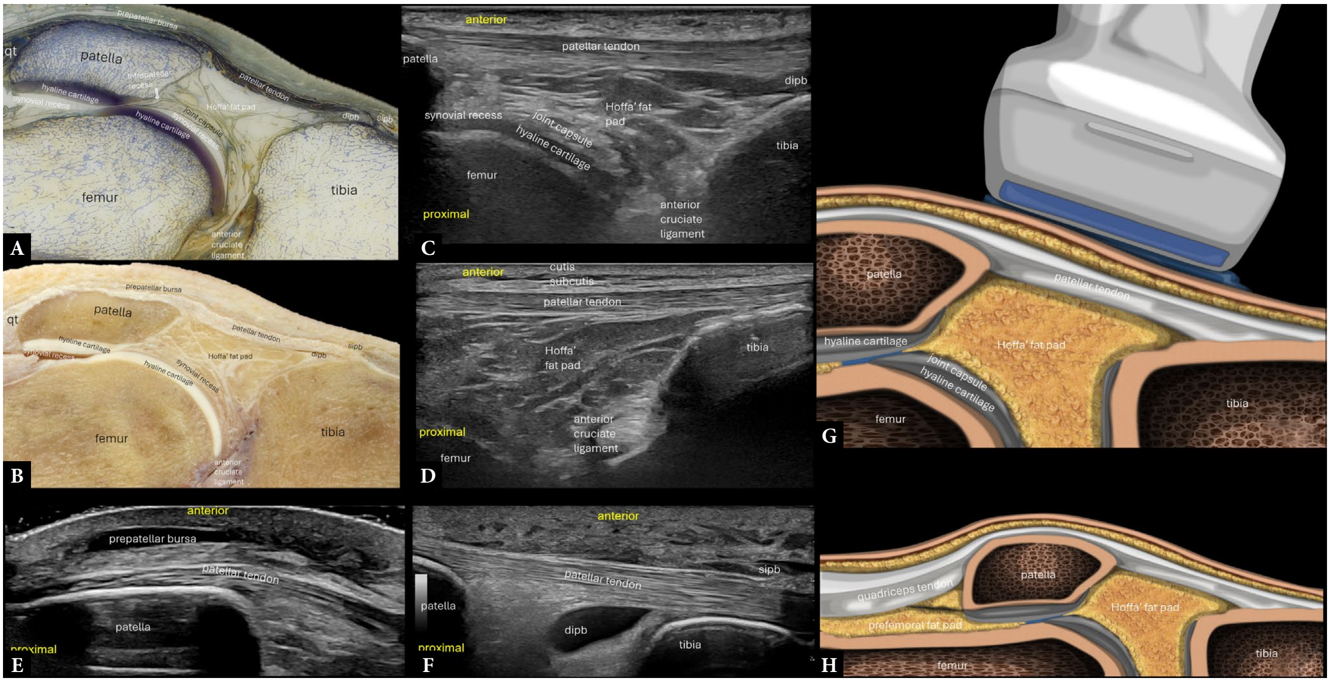

Fig. 5. *Anterior knee, infrapatellar region. Histological (***A***), anatomical (***B***), and ultrasound longitudinal images (***C–F***). Illustrations with probe position in suprapatellar longitudinal (***G–H***).* **C.** *Sagittal sonogram with the knee flexed at 20–30 degrees. Under normal conditions, the patellar bursae are almost not depictable. In full flexion (***D***), the distal normal part of the anterior cruciate ligament becomes visible.* **E** *and* **F** *show pathological cases in which the prepatellar bursa (***E***) and the superficial and deep infrapatellar bursae (respectively sipb and dipb, in* **F***) are distended by fluid. qt – quadriceps tendon*

The infrapatellar recesses – both suprahoffatic and infrahoffatic – occupy the infrapatellar space. The suprahoffatic recess lies inferior to the patella but superior to Hoffa's fat pad, while the infrahoffatic recess is located deep and distal within Hoffa's fat pad. Optimal visualization of the latter occurs when the patient actively pushes their leg toward the examination table. Importantly, not all patients with knee effusion necessarily demonstrate fluid in these infrapatellar recesses.

During maximum knee flexion, the examination can reveal the anterior cruciate ligament's insertion at the intercondylar eminence. Visualization often improves by reducing the frequency setting. The final assessment includes examining the femoral condyles' hyaline cartilage, which can be achieved by tilting the probe beneath the patella and through the Hoffa's fat pad.

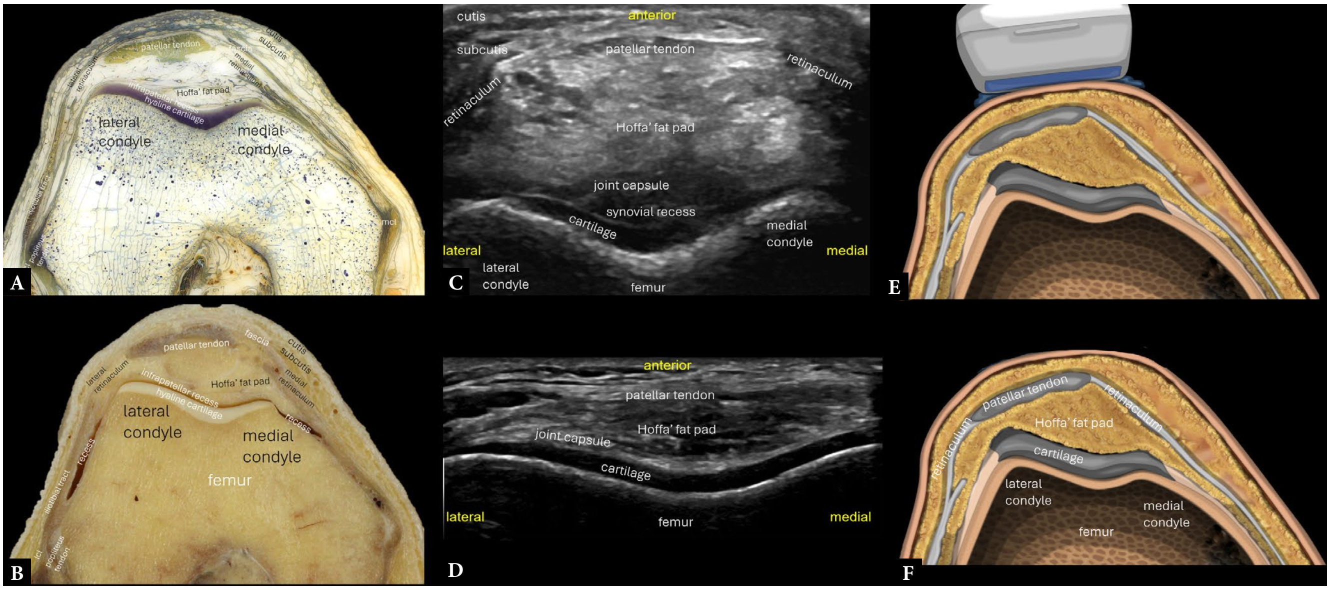

Fig. 6. *Anterior knee, infrapatellar region. Histological (***A***), anatomical (***B***), and transverse sonograms (***C–D***). Illustrations with probe position in suprapatellar longitudinal (***E–F***) In C, by placing the transducer in the axial plane in the infrapatellar region, the femoral trochlea cartilage can be appreciated. However, to improve its depiction, it is suggested to fully flex the knee and place the transducer distal to the patella (***D***). mcl, lcl – medial and lateral collateral ligament*

Medial knee region

The examination of the medial knee structures requires a systematic approach that combines precise positioning with comprehensive anatomical assessment. Beginning with a longitudinal view, we establish orientation using the femur proximally and the tibia distally as key landmarks (Tab. 2). The examination progresses through three distinct phases: initial assessment in extension, evaluation in flexion, and finally, dynamic examination, performed either supine or in a lateral position.

Optimal visualization of medial structures requires specific patient positioning, with the knee in slight 20–30° flexion supported by a pillow, and gentle external rotation. This position facilitates examination of the superior and inferior medial parameniscal recess, which presents a characteristic finger-like appearance with a thin pedunculus originating from the medial femorotibial joint line and extending to a cul-de-sac beneath the deep fibers of the MCL[14].

Assessment of the medial meniscus reveals its complex fibrocartilaginous structure and important ligamentous connections. The meniscus maintains its position through two distinct but related attachments: the meniscotibial ligament (MTL) connecting to the tibia, and the meniscofemoral ligament (MFL), extending to the femur. While these attachments relate to the deep layers of the MCL, they maintain distinct anatomical identities (Fig. 7)[15]. The MCL itself displays a sophisticated layered structure, with deep and superficial components appearing as regular, fibrillar laminae separated by a hypoechoic region containing loose connective tissue and fat[16]. Although a bursa may exist between the MCL's components (MCL bursa)[17–19], it typically remains undetectable under normal conditions.

Comprehensive meniscal evaluation requires both static and dynamic assessment techniques. The examiner should evaluate the structure in both longitudinal and transverse planes, incorporating functional examination through various positions, including standing and lying, with particular attention to movement during flexion and rotation. The ligamentous connections between the meniscus and both femur and tibia require careful static and dynamic evaluation. A small amount of anechoic fluid in the medial recess is considered a normal finding.

Tab. 2. Medial knee region: patient position, scanning technique, and assessed structures

Medial knee region: • Knee medial transverse and longitudinal position: supine position, hip joint in neutral position, knee joint extended and in flexion. The knee joint's medial part is inspected as the leg is rotated externally • Static and dynamic examination (internal and external rotation, valgus and varus stress) • Osseous landmarks: Medial femoral condyle, patella, tibia
Assessed structures: • Medial femorotibial joint cavity • Medial collateral ligament (MCL) (deep and superficial layers) • MCL bursa • Medial patellar retinaculum • Meniscofemoral ligament (MFL) and meniscotibial ligament (MTL) • Medial meniscus • Medial femoral condyle, medial tibial plateau • Medial superior and inferior parameniscal recess • Pes anserine tendons • Insertion of the semimembranosus muscle • Saphenous nerve (medial to the gracilis muscle)

The MCL examination follows its course from the femoral origin to its tibial attachment, noting the superficial MCL's distinctive proximal connection to the semimembranosus tendon's anterior arm and its distal entheseal insertion[20]. The posterior oblique ligament (POL), visible between the medial gastrocnemius tendon and the MCL's posterior border[21], displays three components – superficial, central, and capsular portions – all originating from the femoral adductor tubercle. The superficial extension connects to the proximal tibia alongside the semimembranosus tendon's distal insertion.

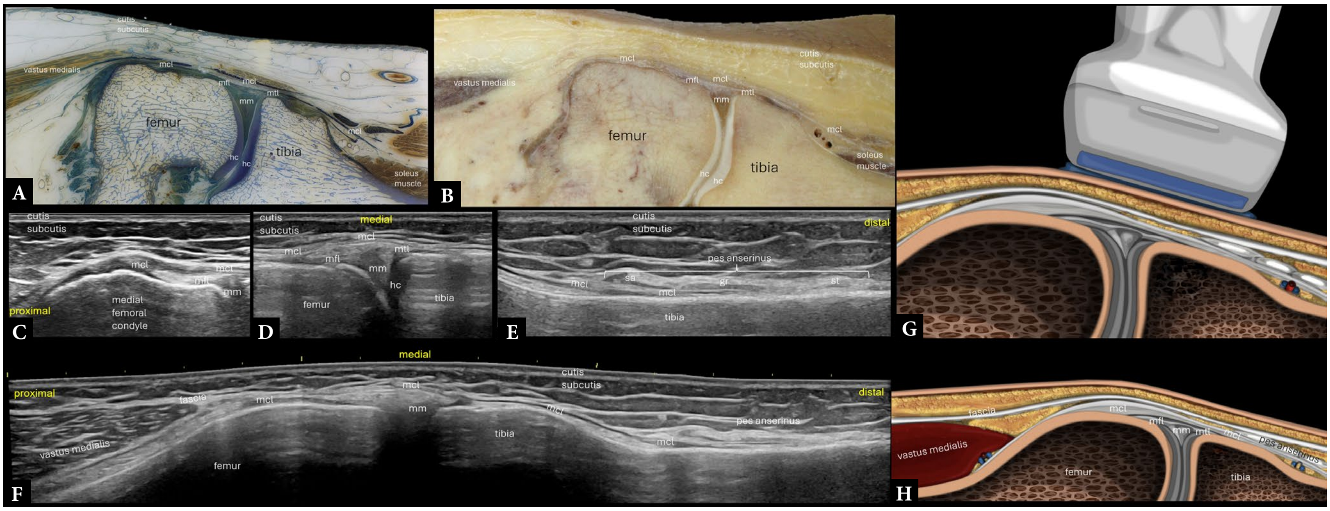

Fig. 7. *Medial knee. Histological (**A**), anatomical (**B**), and longitudinal sonograms (**C–F**). Illustrations with probe position in suprapatellar longitudinal (**G–H**). In **B**, the inferior medial genicular artery can be identified between the tibia and the mcl. **C–E.** Medial collateral ligament (mcl) long-axis, depicted in three subsequent sonograms from proximal (**C**) to distal (**E**). Note in D the menisco-femoral (mfl) and menisco-tibial (mtl) ligaments, which attach to the medial meniscus (mm). In **E**, the distal part of the ligament is superficially crossed by the pes anserinus. **F.** Longitudinal extended field of view of the medial region of the knee. sa – sartorius tendon; gr – gracilis tendon; st – semitendinosus tendon; hc – hyaline cartilage*

The semimembranosus tendon serves multiple functions, including providing an acoustic window for posterior horn evaluation of the medial meniscus before merging anteriorly with the posterior portion of the MCL. The central extension of the POL forms its most prominent component, creating an important attachment to the posteromedial meniscus and integrating smoothly with the posteromedial joint capsule. Dynamic examination of this complex region, particularly the menisco-capsular junction of the medial meniscus's posterior horn, is best performed with the patient prone and actively flexing the knee against resistance.

The pes anserinus complex appears anterior to the distal MCL, where its aponeurotic insertion at the tibial metaphysis consists of the sartorius, gracilis, and semitendinosus tendons. Optimal visualization of the pes anserinus's long axis requires slight anterior rotation (approximately 20°) of the transducer's distal portion. Between the MCL's insertion zones lies the 'tibial tunnel,' containing neurovascular structures – an artery, veins, and the infrapatellar branch of the saphenous nerve (a terminal branch of the femoral nerve) – along with the anterior arm of the semimembranosus insertion. Normal anatomy typically shows no visible superficial or deep anserine bursa, and inflammatory conditions in this region are rare.

Tab. 3. Lateral knee region: patient position, scanning technique, and assessed structures

Lateral knee region: • Knee lateral transverse and longitudinal • Position: supine position, hip joint in neutral position, knee joint extended and in flexion. It is recommended that the patient internally rotate the leg to assess the lateral side of the knee joint • Static and dynamic examination (internal and external rotation, valgus and varus stress in lateral position) • Osseous landmarks: lateral femoral condyle, patella, tibia, fibula
Assessed structures: • Lateral femorotibial joint cavity • Lateral collateral/fibular ligament • Biceps femoris tendon • Joint capsule • Popliteal tendon • Iliotibial band • Anterolateral ligament (anterior lateral complex) • Illiotibial band bursa • Subpopliteal recess • Lateral femoral condyle, lateral tibial plateau • Lateral meniscus • Lateral (parameniscal) recess • Lateral patellar retinaculum • Proximal tibiofibular joint • Peroneal nerve

Lateral knee region

The lateral knee examination requires a methodical approach, combining precise probe positioning with thorough anatomical assessment. Beginning with a longitudinal orientation, initial landmarks are established from the femur proximally to the tibia distally, after which the transducer is adjusted slightly posteriorly toward the fibula (Tab. 3). Optimal visualization requires positioning the knee in 20–30° flexion with slight internal rotation of the leg.

The initial assessment focuses on the lateral femoral condyle and lateral tibial plateau, evaluating the femorotibial joint cavity. A key anatomical relationship appears as the joint capsule courses laterally alongside the ligamentous apparatus to the iliotibial band (ITB) insertion at the Gerdy tuberosity, located anterolateral to the tibial epiphysis (Fig. 8). From the lateral femoral epicondyle, the anterolateral ligament (ALL) emerges as a distinct structure, following a unique anteroinferior path to insert between the fibular head tip and Gerdy's tubercle beneath the lateral tibial plateau[22].

The lateral knee's structural organization differs notably from its medial counterpart, particularly in the parameniscal recesses. Both the superior and inferior lateral recesses exhibit greater expansion than their medial counterparts, primarily due to fat tissue covering

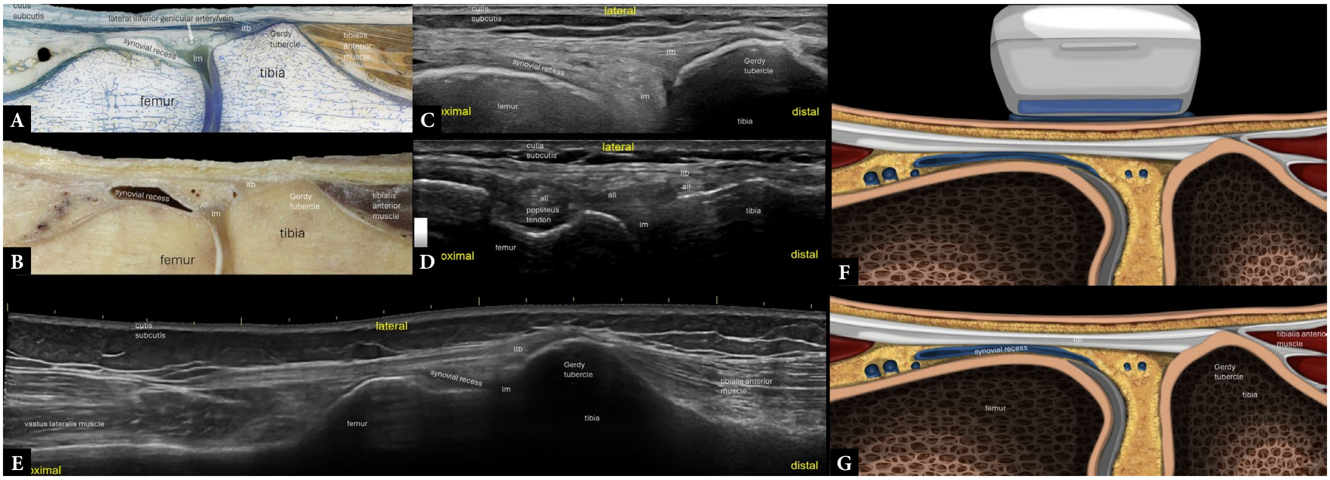

Fig. 8. *Lateral knee. Histological (**A**), anatomical (**B**), and longitudinal sonograms (**C–E**). Illustrations with probe position in suprapatellar longitudinal (**F–G**) In **C**, the long-axis of the distal iliotibial band (itb) is demonstrated at its insertion at the Gerdy's tubercle. In **D**, the distal part of the probe is almost fixed, whereas the proximal part is rotated near the insertion of the lateral collateral ligament, to depict a thin ligamentous structure, the anterolateral ligament (all).* **E.** *Longitudinal extended field of view of the lateral distal part of the thigh and proximal part of the leg. lm – lateral meniscus*

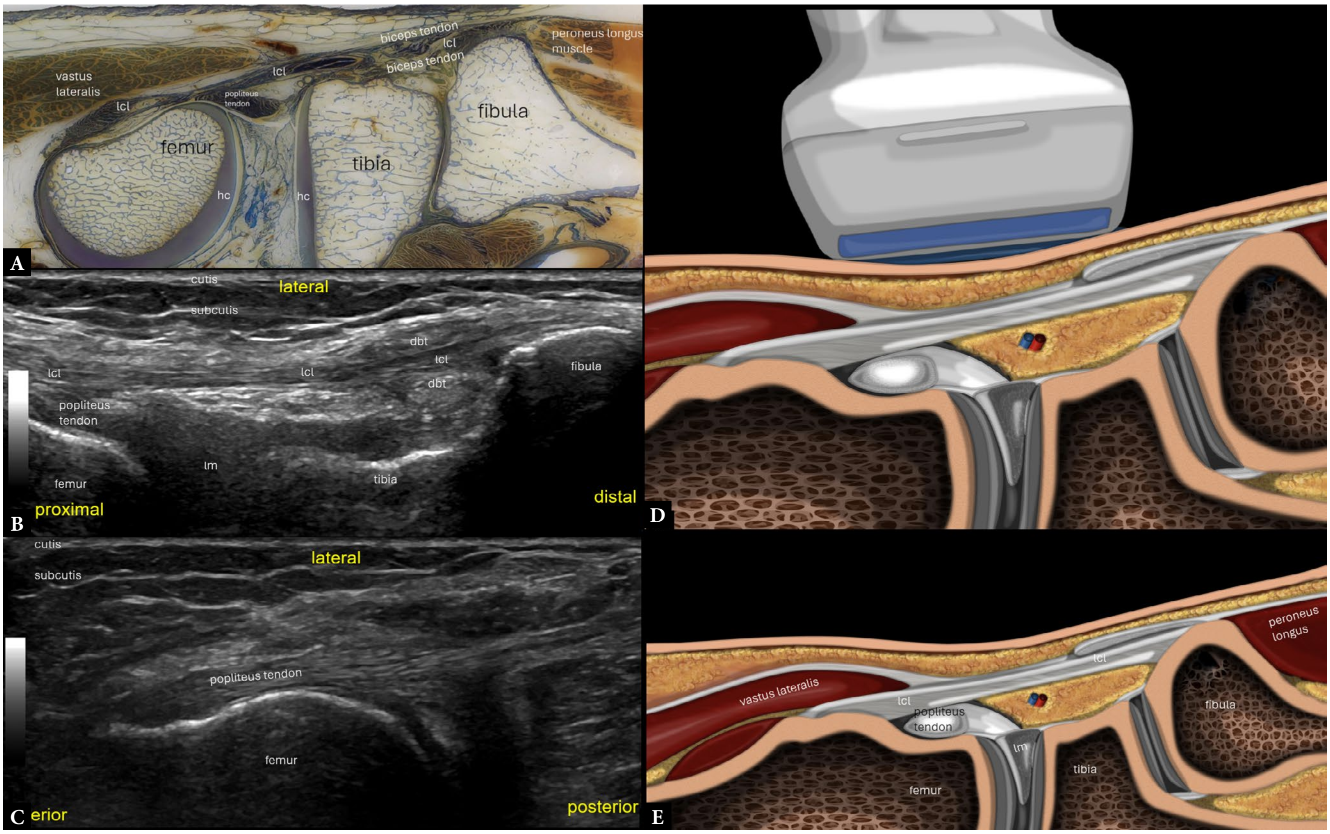

Fig. 9. *Lateral knee. Histological section (**A**) and sonograms (**B, C**). Illustrations with probe position in suprapatellar longitudinal (**D–E**) In B, the transducer is placed over the long-axis of the lateral collateral ligament (lcl). Note that the distal biceps tendon (dbt) bifurcates just proximally to its insertion, so that one component is superficial and the other deep to the ligament. This is a normal appearance. In **C**, rotating the transducer by 90° from the position in **B**, the proximal long-axis of the popliteus tendon is depicted. lm – lateral meniscus; hc – hyaline cartilage*

them, as opposed to the more superficially located lateral collateral ligament. Dynamic and static assessment of the lateral meniscus is essential, with the inferior genicular artery serving as a useful landmark lateral to the outer edge of the meniscus.

The lateral collateral ligament (LCL) presents as a distinct cord-like extra-articular structure with characteristic fibrillar patterning, remaining independent of the meniscus and joint capsule (Fig. 9). It traces a clear path from its origin at the lateral femoral condyle's external tuberosity to its insertion at the fibular head's lateral edge, where it joins the distal biceps femoris tendon (BT). The relationship between the LCL and BT components shows notable anatomical variability, with the distal biceps tendon typically encircling the LCL.

A complex anatomical relationship exists between the LCL and BT, potentially including an intervening bursa. The biceps tendon, comprising both the short and long heads, demonstrates five distinct patterns of interaction with the LCL:

- Type I (most common): The LCL passes between the anterior and direct arms of the long head;
- Type II: The anterior arm of the long head connects directly to the LCL;
- Type III: The LCL and BT form a conjoint tendon;
- Type IV: The LCL lies anterior to the BT;
- Type V: The LCL is positioned posterior to the BT's direct head.

The popliteus muscle, uniquely positioned as an intracapsular but extrasynovial structure, originates in the femoral popliteal fossa before its tendon inserts into the femoral popliteal groove. A small synovial recess typically appears beneath the popliteal tendon, often containing a physiological amount of anechoic fluid[23]. Similarly, the presence of anechoic fluid in the lateral recess represents a normal finding. The subpopliteal recess displays a characteristic C-shaped configuration, originating at the lateral femorotibial joint line and curving around the lateral femoral condyle to terminate within the popliteal groove.

Posterior knee region

Examination of the posterior knee structures can be performed in either prone or standing position (Tab. 4), with the region systematically divided into three anatomically distinct areas: medial, middle, and lateral. This organization allows for comprehensive evaluation of all relevant structures.

The medial aspect examination (Fig. 10) follows a layered approach, beginning superficially and progressing deeper. The assessment includes the sartorius muscle, followed by the gracilis and semitendinosus tendons, the semimembranosus muscle, and finally the medial head of the gastrocnemius muscle. The gracilis tendon maintains a consistent anatomical relationship posterior to the sartorius muscle, while the semitendinosus tendon lies superficial to the proximal semimembranosus muscle. At the posteromedial tibial epiphysis, the semimembranosus tendon forms its direct attachment. Dynamic assessment of the menisco-capsular junction of the medial meniscus's posterior horn can be performed with the patient prone and actively flexing the knee against resistance.

The semimembranosus region contains several important bursal structures. The semimembranosus bursa surrounds its namesake tendon[24], while the semimembranosus-gastrocnemius bursa (Baker's cyst when distended) occupies the space between the semimembranosus tendon and the medial gastrocnemius head. This bursal complex has two components: a smaller deep portion between the posterior knee and the medial gastrocnemius head, communicating with the joint through a capsular opening, and a larger superficial component overlying the medial gastrocnemius in the subcutaneous tissues. Optimal evaluation of the semimembranosus-gastrocnemius bursa is achieved in the standing position after joint loading, particularly when searching for subtle fluid collections. Dynamic assessment of the relationship between the tendons during knee flexion and extension in the prone position helps evaluate for potential friction. Deep to these structures, the posterior horn of the medial meniscus can be visualized, along with the medial femoral condyle proximally and the tibial plateau's anechoic hyaline cartilage.

Tab. 4. Posterior knee region: patient position, scanning technique, and assessed structures

Posterior knee region • Knee posterior transverse and longitudinal • Position: prone position or standing, knee joint extended and in flexion • Static and dynamic examination (internal and external rotation, active flexion and extension) • Osseous landmarks: femoral condyles, tibia, fibula
Assessed structures: • Medial and lateral condyle • Gastrocnemius muscle (medial and lateral heads) • Medial: – Sartorius, gracilis, semitendinosus and semimembranosus muscles – Pes anserinus – Semimembranosus-gastrocnemius bursa ("Baker's cyst") in between the semimembranosus tendon and the medial gastrocnemius muscle – Semimembranosus bursa • Lateral: – Biceps femoris muscle – Plantaris muscle – Fabella (variation present in up to 40%) – Fabellofibular ligament – Arcuate popliteal ligament – Peroneal nerve • Posterior horns of the medial and lateral menisci • Posterior cruciate ligament • Posterior joint capsule • Vascular-nerve bundle: superficial: tibial nerve; intermediate: popliteal vein; profound: popliteal artery (elevate feet for vein assessment)

The examination of the middle compartment (Fig. 10) centers on the popliteal fossa, beginning with a transverse view to identify the femoral condyles and neurovascular structures. The tibial nerve appears most superficially, followed by the popliteal vein and, most deeply, the popliteal artery. Low-frequency settings enable visualization of the posterior joint capsule and posterior cruciate ligament in an oblique plane (Fig. 11).

The lateral aspect reveals a complex layered anatomy. A longitudinal approach demonstrates the biceps femoris muscle proximally and the lateral gastrocnemius distally. The biceps tendon, formed by the convergence of its two heads at the popliteal gap's proximal margin, inserts into the fibular head, with its distal bifurcation encircling the LCL. An anterior bundle from the short head extends to the tibial plateau[25]. Deep structures include the posterior horn of the lateral meniscus, positioned between the lateral femoral condyle proximally and the tibia and fibular head distally and laterally. The common peroneal nerve and its branches (deep, recurrent and superficial) course along the lateral aspect, posterior to the biceps tendon (Fig. 12)[26].

The posterolateral knee complex demonstrates three distinct anatomical layers crucial for both imaging and clinical assessment[27].

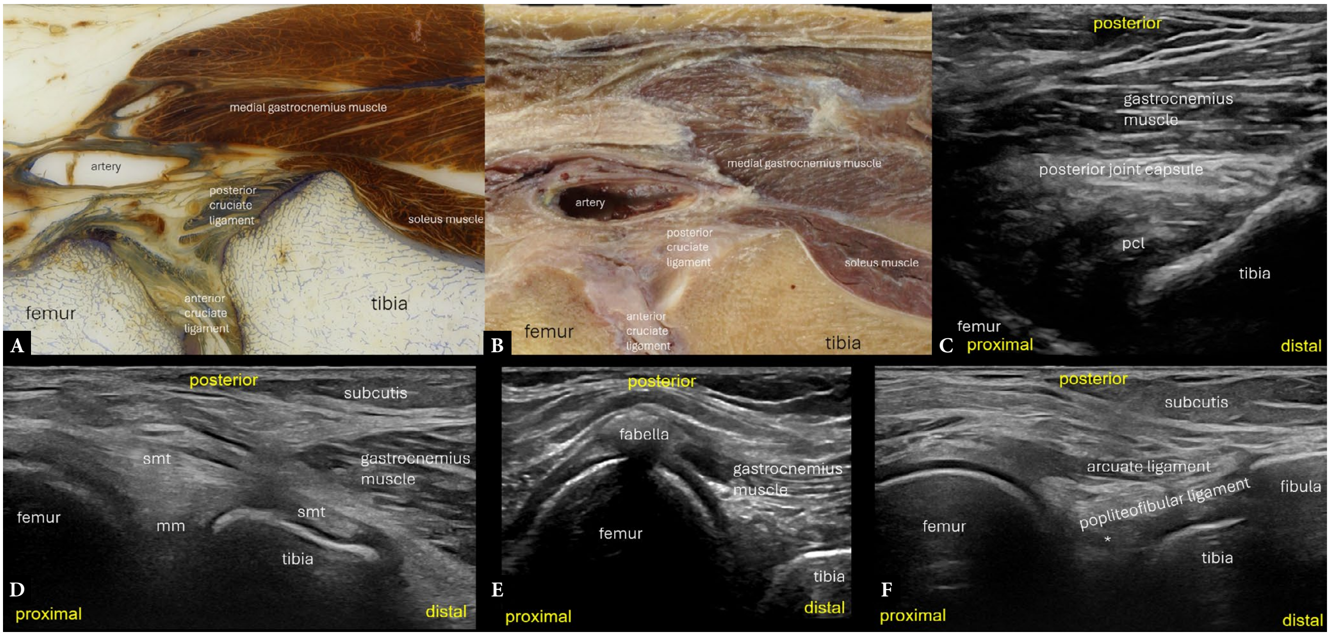

Fig. 10. *Posterior knee. Histological (***A***), anatomical (***B***), and longitudinal sonograms (***C–F***).* **C** *represents a sagittal posterior median sonogram corresponding to* **A** *and* **B***. The posterior collateral ligament (pcl), in particular its distal part, can be appreciated.* **D.** *Medial posterior sonogram obtained along the course of the direct tendon arm of the semimembranosus muscle (smt).* **E.** *Lateral longitudinal sonogram depicts a common variation (fabella, a sesamoid bone).* **F.** *The arcuate and popliteofibular ligaments are shown at the posterolateral aspect of the knee. pcl – posterior cruciate ligament; smt – semimembranosus tendon; mm – medial meniscus; asterisk – popliteus myotendinous junction*

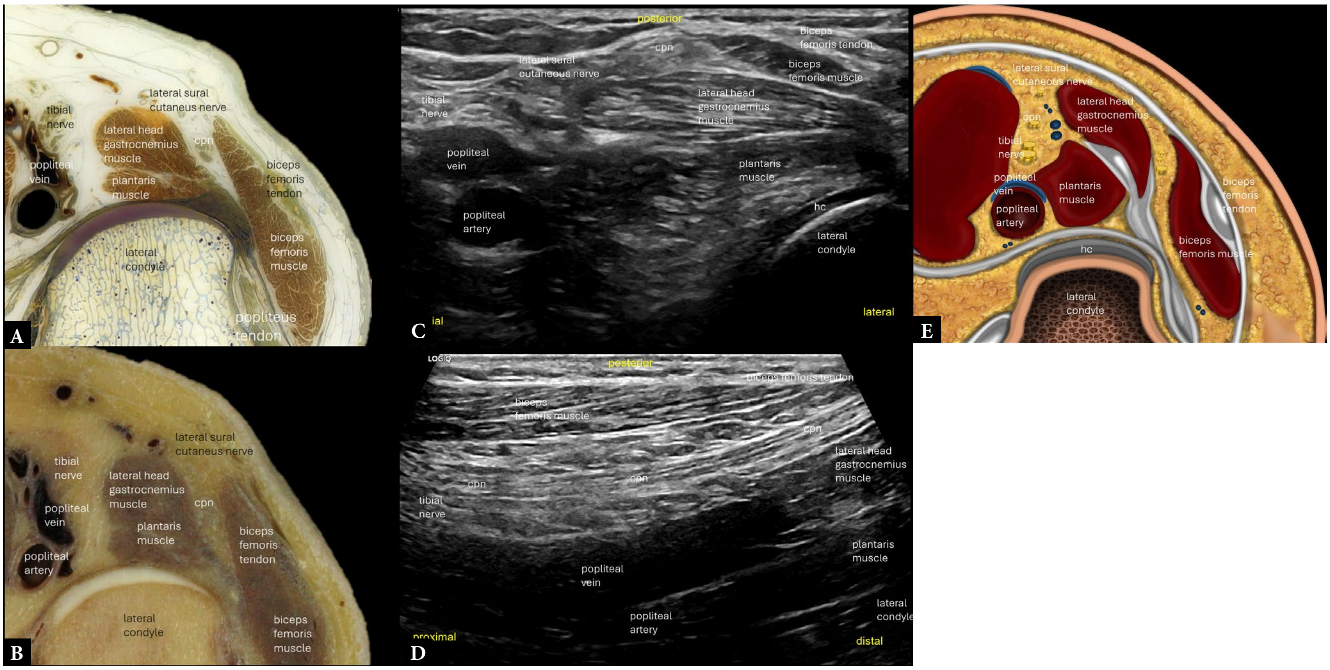

Fig. 11. *Posterior knee, lateral region. Histological (***A***) and anatomical (***B***) sections.* **C.** *Axial sonogram corresponding to* **A** *and* **B***. Illustration (***E***).* **D** *Longitudinal oblique sonogram of the lateral part of the knee, obtained along the long-axis of the common peroneal nerve (cpn). Due to the slightly oblique course of the nerve, the vessels are only partially depicted along their long-axis. hc – hyaline cartilage*

The superficial layer, comprising the posteriorly located biceps femoris tendon and anterior iliotibial band, provides dynamic stability. The intermediate layer contains the posterior lateral collateral ligament and anterior lateral patellar retinaculum, offering primary static stabilization against varus stress. The deep layer includes the fabellofibular and popliteal arcuate ligaments, reinforcing the posterior capsule. The popliteal tendon lies deep to all three layers, serving as a reliable anatomical landmark. Thorough evaluation requires systematic assessment of each layer from superficial to deep, incorporating both static and dynamic testing to fully assess structural integrity.

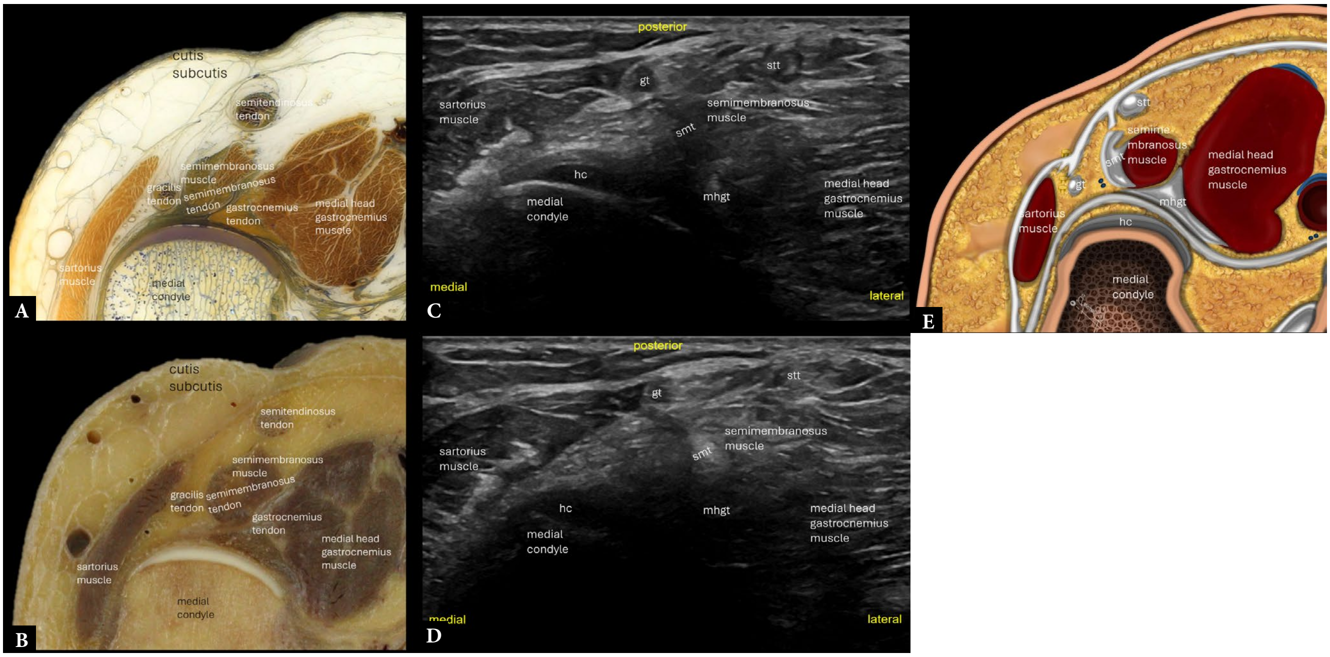

Fig. 12. *Posterior knee, medial region. Histological (***A***), anatomical (***B***), and transverse sonograms (***C, D***). Illustration (***E***). Note that the ultrasound images (***C, D***) appear different because the probe was slightly tilted to use anisotropy to enhance tendinous structures. Therefore, due to the different courses, the gracilis (gt), semitendinosus (stt), and semimembranosus (smt) tendons appears hypoechoic in* **C** *and hyperechoic in* **D***, whereas the medial head of the gastrocnemius muscle (mght) is hyperechoic in* **C** *and hypoechoic in* **D***. hc – hyaline cartilage*

Practical applications and tips

Understanding the interplay between technical optimization and anatomical knowledge enhances the quality of ultrasound examinations. Small details in technique often make a significant difference – such as maintaining the ultrasound probe at a precise 90-degree angle to minimize artificial anisotropy, using the heel-toe rocking motion for curved surfaces (e.g. bony insertions of ligaments/tendons), and applying the probe's elevation capability for deeper structures. The 'elevate and tilt' technique, particularly useful when examining the posterolateral corner, involves first increasing the depth setting to locate deep structures, then gradually decreasing it while maintaining structure visualization.

Image optimization extends beyond basic depth and gain adjustments. When examining highly reflective structures like the patellar surface, reducing the gain in the near field while increasing it in the far field helps balance image quality. Harmonics settings prove particularly valuable when examining the posterior horns of the menisci, enhancing border definition while reducing artefact interference.

Challenging scenarios require specific solutions. For patients with limited mobility, modified positioning techniques can be employed, such as using cushions for partial flexion or side supports for stability during stress maneuvers. In cases of significant muscle bulk, starting with panoramic imaging helps establish a reference frame before conducting a detailed structural examination. For patients who have with difficulty maintaining position, short-axis scanning with subsequent long-axis correlation often proves more efficient than traditional long-axis-first approaches.

Advanced dynamic assessment can reveal subtle biomechanical relationships. Combining active and passive movements during the examination – for instance, alternating between patient-initiated and examiner-guided motion – provides complementary information about structural behavior. This approach is particularly beneficial for evaluating the complex relationships between the posterior horns of the menisci and their capsular attachments.

Conclusions

While ultrasound has certain limitations, particularly when assessing deep intra-articular structures, it offers unique advantages for knee evaluation through its dynamic capabilities and high-resolution imaging of superficial structures. High-resolution knee musculoskeletal ultrasonography requires the integration of detailed anatomical knowledge with practical scanning expertise to ensure accurate structural evaluation. The complex anatomy of the posteromedial and posterolateral corners particularly benefits from a systematic, layer-by-layer ultrasound approach that reveals the intricate relationships between structures.

Contemporary high-resolution musculoskeletal ultrasonography enhances knee imaging by connecting anatomical cross-sections and intricate histology to specific anatomical features, supported by dynamic assessment capabilities that complement static imaging modalities such as MRI. This approach allows real-time visualization of structural relationships and biomechanical interactions, especially valuable in complex regions where multiple structures converge. The ability to perform precise, real-time guided diagnostic and therapeutic interventions, combined with detailed assessment of peripheral nerves and soft tissues, makes ultrasound an invaluable tool in modern knee imaging.

Understanding the layered architecture and functional anatomical complexes of the knee enables examiners to systematically identify and evaluate structures, while recognizing normal variants and potential pitfalls. This comprehensive approach to knee ultrasonography – integrating anatomical knowledge with practical scanning expertise – provides a foundation for accurate diagnosis and targeted intervention in clinical practice.

Acknowledgements

We acknowledge the use of Grammarly (https://app.grammarly.com/) to check for spelling and grammatical errors. We confirm that no AI-generated content has been presented as our work.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

Author contributions

Original concept of study: GT, RM, FM. Writing of manuscript: GT, RM, FM. Analysis and interpretation of data: GT, RM, VR, MB, MGP, FM. Final acceptation of manuscript: GT, RM, VR, MB, MGP, GASB, FM. Collection, recording and/or compilation of data: GT, RM, MB, GASB, MT, MMG. Critical review of manuscript: GT, RM, VR, MB, MGP, GASB, FM, MMG.

References

1. Giokits-Kakavouli G, Karokis D, Raftakis I, Siagkri C: Ultrasound of the knee in Rheumatology: Pitfalls, what is new? Mediterr J Rheumatol 2016; 27: 151–160.
2. De Maeseneer M, Marcelis S, Boulet C, Kichouh M, Shahabpour M, de Mey J, Cattrysse E: Ultrasound of the knee with emphasis on the detailed anatomy of anterior, medial, and lateral structures. Skeletal Radiol 2014; 43: 1025–1039. doi: 10.1007/s00256-014-1841-6.
3. Hauser NH, Hoechel S, Toranelli M, Klaws J, Müller-Gerbl M: Functional and Structural Details about the Fabella: What the Important Stabilizer Looks Like in the Central European Population. Biomed Res Int 2015; 2015: 343728. doi: 10.1155/2015/343728.
4. Tamborrini G, Bianchi S: Ultraschall des Knies (adaptiert nach SGUM-Richtlinien) [Ultrasound of the Knee (Adapted According to SGUM Guidelines)]. Praxis (Bern 1994). 2020; 109: 991–1000. German. doi: 10.1024/1661-8157/a003540.
5. Bianchi S, Créteur V, Moraux A, Tamborrini G : Ultrasound. In: Davies M, James S, Botchu R (eds): Imaging of the Knee. Medical Radiology. 2023, Springer, Cham. doi: 10.1007/174_2022_351.
6. Pirri C, Stecco C, Güvener O, Mezian K, Ricci V, Jačisko J *et al.*: EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for Knee. Am J Phys Med Rehabil 2023; 102: e67–e72. doi: 10.1097/PHM.0000000000002173.
7. Wu WT, Chang KV, Naňka O, Mezian K, Ricci V, Wang B, Özçakar L: Ultrasound Imaging of the Articularis Genus Muscle: Implications for Ultrasound-Guided Suprapatellar Recess Injection. Diagnostics (Basel) 2024; 14: 183. doi: 10.3390/diagnostics14020183.
8. Grob K, Gilbey H, Manestar M, Ackland T, Kuster MS: The Anatomy of the Articularis Genus Muscle and Its Relation to the Extensor Apparatus of the Knee. JB JS Open Access 2017; 2: e0034. doi: 10.2106/JBJS.OA.17.00034.
9. Aguiar RO, Viegas FC, Fernandez RY, Trudell D, Haghighi P, Resnick D: The prepatellar bursa: cadaveric investigation of regional anatomy with mri after sonographically guided bursography. AJR Am J Roentgenol 2007; 188: W355-8.
10. Ricci V, Özçakar L: Ultrasonographic Imaging of the medial and lateral pouches in the knee: EURO-MUSCULUS/USPRM protocol(s) revisited. Ann Phys Rehabil Med 2019; 62: 203–204. doi: 10.1016/j.rehab.2018.09.002.
11. Morrison JL, Kaplan PA: Water on the knee: cysts, bursae, and recesses. Magn Reson Imaging Clin N Am 2000; 8: 349–370.
12. Manske RC, Page P, Voight M, Wolfe C: Musculoskeletal Ultrasound: An Essential Tool in Diagnosing Patellar Tendon Injuries. Int J Sports Phys Ther 2023; 18: 84448. doi: 10.26603/001c.84448.
13. Wu WT, Chang KV, Wu KW, Mezian K, Ricci V, Özçakar L: Dynamic Ultrasonography for Imaging Pediatric Fat Pad Herniation through the Lateral Patellar Retinaculum. Diagnostics (Basel) 2022; 12: 2523. doi: 10.3390/diagnostics12102523.
14. Kikuchi K, Tabuchi K, Inoue S, Yamashita A, Kinouchi S, Hashida R *et al.*: Anatomical evaluation of the superficial medial collateral ligament distal tibial attachment of the knee. Clin Anat 2024 Jun 6. doi: 10.1002/ca.24192.
15. Ricci V, Mezian K, Cocco G, Donati D, Naňka O, Farì G, Özçakar L: Anatomy and ultrasound imaging of the tibial collateral ligament: A narrative review. Clin Anat 2022; 35: 571–579. doi: 10.1002/ca.23864.
16. Śmigielski R, Becker R, Zdanowicz U, Ciszek B: Medial meniscus anatomy – from basic science to treatment. Knee Surg Sports Traumatol Arthrosc 2015; 23: 8–14. doi: 10.1007/s00167-014-3476-5.
17. Galletti L, Ricci V, Andreoli E, Galletti S: Treatment of a calcific bursitis of the medial collateral ligament: a rare cause of painful knee. J Ultrasound 2019; 22: 471–476. doi: 10.1007/s40477-018-0353-y.
18. Ricci V, Özçakar L, Galletti L, Domenico C, Galletti S: Ultrasound-Guided Treatment of Extrusive Medial Meniscopathy: A 3-Step Protocol. J Ultrasound Med 2020; 39: 805–810. doi: 10.1002/jum.15142.
19. Nakase J, Yoshimizu R, Kimura M, Kanayama T, Yanatori Y, Tsuchiya H: Anatomical description and short-term follow up clinical results for ultrasound-guided injection of medial collateral ligament bursa: New conservative treatment option for symptomatic degenerative medial meniscus tear. Knee 2022; 38: 1–8. doi: 10.1016/j.knee.2022.06.001.
20. LaPrade RF, Engebretsen AH, Ly TV, Johansen S, Wentorf FA, Engebretsen L: The anatomy of the medial part of the knee. J Bone Joint Surg Am 2007; 89: 2000–2010. doi: 10.2106/JBJS.F.01176.
21. D'Ambrosi R, Corona K, Guerra G, Cerciello S, Ursino C, Ursino N, Hantes M: Posterior oblique ligament of the knee: state of the art. EFORT Open Rev 2021; 6: 364–371. doi: 10.1302/2058-5241.6.200127.
22. Margenfeld F, Tamborrini G, Beck M, Zendehdel A, Raabe O, Poilliot A, Müller-Gerbl M: The feasibility of ultrasound-guided latex labeling of the anterolateral ligament in anatomical dissection – A cadaveric study. Ann Anat 2024; 256: 152324. doi: 10.1016/j.aanat.2024.152324.
23. Ricci V, Özçakar L: Ultrasound imaging for lateral knee pain: popliteus tendon highlighted. Med Ultrason 2018; 20: 403–404. doi: 10.11152/mu-1616.
24. Onishi K, Sellon JL, Smith J: Sonographically Guided Semimembranosus Bursa Injection: Technique and Validation. PM R 2016; 8: 51–57. doi: 10.1016/j.pmrj.2015.05.015.
25. Zhou M, Ishizawa A, Akashi H, Suzuki R, Bando Y: Bifurcated distal biceps brachii tendon coexisting with separated bicipital aponeurosis: a complex variational case report. Anat Sci Int 2023; 98: 611–617. doi: 10.1007/s12565-023-00719-5.
26. Becciolini M, Pivec C, Riegler G: Ultrasound Imaging of the Deep Peroneal Nerve. J Ultrasound Med 2021; 40: 821–838. doi: 10.1002/jum.15455.
27. Wu WT, Onishi K, Mezian K, Naňka O, Wang B, Su DC *et al.*: Ultrasound imaging of the posterior lateral corner of the knee: a pictorial review of anatomy and pathologies. Insights Imaging 2024; 15: 39. doi: 10.1186/s13244-024-01606-x.