Imaging Anatomy of Normal Knee Joint using 3.0 T MRI- A pictorial review

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ABSTRACT

With the use of high resolution imaging of knee on 3.0 T MRI, the ligamentous and cartilaginous structures can be elucidated in better details, and diagnosis that had been ambiguous in ye past can be made more confidently now. High quality image with excellent soft tissue contrast is obtained in transverse, sagittal and coronal imaging planes due to multiplanar capability of MRI. The functional and imaging anatomy can be useful to radiologists, orthopedecians, surgeons, physicians, anatomist, residents and all others who are interested in knee joint.

Key words: *imaging anatomy, knee joint, magnetic resonance imaging*

INTRODUCTION

The knee joint is the largest and most superficial joint of the body formed by femur, tibia and patella. Magnetic resonance imaging (MRI) of the knee has developed into one of the most commonly requested examinations in radiology not just because many people injure their knees but because of its high accuracy in depicting internal derangements with its multiplanar capabilities and excellent soft-tissue contrast. It is regarded as the top imaging and diagnostic tool as a result of its ability to evaluate a wide range of anatomyand pathology varying from ligamentous injuries to articular cartilage lesions of the knee joint.[1,2] Due to the potential advantage of obtaining detailed images, the 3.0T MR system suggests a practical utility for fine demonstration of the knee morphology and improves the diagnostic performance.[3,4] The aim of this article is to provide a background in the functional and radiological anatomy of normal knee joint.

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FUNCTIONAL ANATOMY

The knee joint is primarily a hinge type of synovial joint, allowing flexion and extension; however, the hinge movements are combined with gliding and rolling, and with rotation about a vertical axis. The knee joint is relatively weak mechanically because of the incongruence of its articular surfaces. The stability of the knee joint depends on (a) the strength and actions of the surrounding muscles and their tendons, and (b) the ligaments that connect the femur and tibia.[5,6] The knee comprises two joints, the tibiofemoral joint, with its medial and lateral compartments, and the patellofemoral joint. The menisci and ligaments are fundamental to the maintenance of joint stability.[7]

MRI TECHNIQUE

The techniques and imaging planes discussed here is oriented toward the routine screening examination that is commonly used to evaluate most articular and periarticular disorders of the knee. Typically, the patient is placed in the supine position with the knee placed in a cylindrical coil (often called an "extremity" or "knee" coil). The knee may be externally rotated 15° to 20°, as this position

is more comfortable to patient and also facilitate visualization of the ACL on sagittal images. The knee should be flexed slightly (5° to 10°) to increase the accuracy of assessing the patellofemoral compartment and patellar alignment. Knee MRI examinations usually include images acquired in the transverse, sagittal, and coronal imaging planes. The coverage should include all the anterior, posterior, medial, and lateral supporting structures of the knee, though not all structures need to be included in every imaging plane. Superiorly, the distal aspects of the quadriceps tendon and suprapatellar bursa should be included. The distal insertions of the patellar tendon and pes anserinus tendons should be included inferiorly. The field of view (FOV) for the standard sequences, should be 16 cm or smaller. Slice thickness in the sagittal and coronal planes of 4 mm or less is necessary to demonstrate subtle meniscal pathology. A matrix of 256 × 192 or 256 × 256 is considered standard. A typical imaging protocol will be composed of one or more of the following pulse sequence types - Spin-echo, fast (turbo) spin-echo, and gradient-recalled sequences.In this article, MR imaging of a healthy volunteer was performed on a 3.0 T MR imaging unit (Philips, Achieva)[8,9,10]

BASIC IMAGING ANATOMY ANTERIOR CRUCIATE LIGAMENT (ACL)

The anterior cruciate ligament (ACL), the weaker of the two cruciate ligaments, arises from the anterior intercondylar area of the tibia, just posterior to the attachment of the medial meniscus. It extends superiorly, posteriorly, and laterally to attach to the posterior part of the medial side of the lateral condyle of the femur. The ACL prevents posterior displacement of the femur on the tibia. With the knee joint flexed, the ACL prevents the tibia from being pulled anteriorly.

The ACL is best seen on sagittal oblique images with slices oriented parallel to the cortex of the lateral femoral condyle as a low signal intensity band.

ACL has two main fiber bundles:anteromedial bundle (AMB) and posterolateral bundle (PLB). AMB forms the anterior border of the ACL, and it is easily visualized in sagittal images and also easily damaged. Normally, signal intensity on T1-weighted and spin-density images at the tibial insertion is increased, presumably the result of either interposed fat or the decreased density of the ligament itself.

Coronal and axial images are useful in confirming the findings made on sagittal images.

ACL attaches to the tibia at the site spreading like a fan between the tibial spine and the anterior horn of the medial meniscus and it can be best demonstrated on coronal image. Axial images depict the ACL as a low signal band that is flattened against the medial surface of the lateral femoral condyle.

POSTERIOR CRUCIATE LIGAMENT (PCL)

The posterior cruciate ligament (PCL), the stronger of the two cruciate ligaments, arises from the posterior intercondylar area of the tibia. It passes superiorly and anteriorly on the medial side of the ACL to attach to the anterior part of the lateral surface of the medial condyle of the femur. The PCL prevents anterior displacement of the femur on the tibia. With the knee joint flexed, the PCL prevents the tibia from being pulled posteriorly.

PCL consists of two main fibrous bundles, that is, thicker anterolateral bundle and thinner posteromedial bundle. In normal condition, it is impossible to differentiate these two on MRI, and PCL appears as a one band with homogeneous texture. When PCL is damaged, only one of the two bundles may be torn.

Sagittal images best depict the PCL, which appears as a uniformly low-signal-intensity structure with a nearly horizontal takeoff at the femoral origin and then an abrupt descent at about 45 degrees to the tibia. This angled portion of the ligament is normally directed toward the femur.

In up to two thirds of patients, the meniscofemoral ligaments of Humphrey's and Wrisberg's are seen as low-signal-intensity dots anterior and posterior to the PCL respectively.

MEDIAL COLLATERAL LIGAMENT (MCL)

The tibial or medial collateral ligament (MCL) is often conceptualized as a single ligamentous band extending from the medial femoral condyle to the medial tibial plateau.

MRI studies have demonstrated that the medial knee anatomy is much more complicated. The three layers, numbered from superficial to deep, make up the joint capsule and ligamentous structures, including the MCL. Together, they function to restrain against valgus laxity during knee extension.

- **Layer I:** Thin sheet that overlies the two heads of the gastrocnemius and the structures of the popliteal fossa.

- **Layer II:** Superficial layer of the MCL (alternatively called tibial collateral ligament). These fibers extend from the medial epicondyle of the femur to the tibia, attaching about 2 cm below the joint line and then extending 3 to 4 cm more distally across the medial concavity of the proximal tibia, where fat and blood vessels are normally also present. Anteriorly, Layer II blends with Layer I through the split to form the medial patellar retinaculum. Posteriorly, it blends with Layer III via the posterior oblique ligament.

- **Layer III:** Deepest layer of the MCL called medial capsular ligament, which is continuous with the medial joint capsule.

Fibrofatty tissue fills the space between Layer I and II, and the tendons of semitendinosus and gracilis run through this space.

LATERAL SUPPORTING STRUCTURES INCLUDING LATERAL COLLATERAL LIGAMENT (LCL)

The posterolateral corner of the knee is composed of ligaments, muscles, and tendons that are static restraints to posterior translation, varus angulation, and external rotation of the knee. Collectively referred to as the posterolateral (or arcuate) ligament complex, they include the fibular ligament or LCL, popliteus muscle and tendon, popliteofibular ligament, biceps femoris tendon, fabellofibular ligament, arcuate ligament, and lateral head of the gastrocnemius.

It consists of three layers (superficial to deep):

Layer I: Has two parts: the iliotibial band (ITB) and its expansion anteriorly and the superficial portion of the biceps femoris tendon (BFT) and its expansion posteriorly.

Layer II: Anteriorly it is formed by the lateral patellar retinaculum, and laterally by the lateral collateral ligament (LCL, also known as fibular collateral ligament).

Layer III: This is the deepest layer which is the lateral part of the joint capsule and includes fabellofibular ligament and arcuate ligament.

LCL arises at the lateral femoral epicondyle above the popliteal groove and just anterior to the origin of the lateral head of the gastrocnemius. It runs down to form a conjoint tendon with BFT near the attachment site of the fibular head, where it forms a V-shape. However, BFT belongs to the Layer I and the LCL belongs to the Layer II, anatomically and it is uncommon to be able to visualize this V-shape in a single sagittal image.

The popliteus tendon originates within the popliteal groove of the lateral femoral condyle

just anterior and inferior to the proximal attachment of the LCL. It courses inferiorly and medially over its sulcus in the lateral femoral condyle and then meets its muscle belly posteromedially and deep to the arcuate ligament. It attaches to the posteromedial surface of the proximal tibia.

The arcuate ligament is a Y-shaped thickening of the knee joint capsule, and it has medial and lateral limbs. It extends superiorly from its attachment at the styloid process of the fibula to the level of the popliteus muscle. The medial limb is arcuate; it fans out over the popliteus muscle, blends with fibers of the oblique popliteal ligament, and attaches proximally to the posterior knee capsule. The lateral limb ascends along the deep portion of the capsule to its proximal attachment at the lateral femoral condyle.

In the 20% of individuals who possess a fabella, the fabellofibular ligament extends from the fabella to the styloid process of the fibula. In the remainder, the fabellofibular ligament extends farther superiorly to attach to the posterolateral surface of the lateral femoral condyle.

MENISCI

The menisci of the knee are two C-shaped fibrocartilaginous disks with concave superior surfaces that articulate with the convex femoral condyles and flat inferior surfaces that set on the peripheral margins of the tibial plateau. They are thick peripherally and thin centrally and have sharp inner free edges.

The medial meniscus is semi-lunar (like a half-circle) and is typically larger than the lateral meniscus. The width of the medial meniscus gradually tapers from posterior to anterior, resulting in a wider posterior horn that is almost twice the size of the anterior horn. The anterior horn attaches to the tibial plateau anterior to the anterior horn of the lateral meniscus and anterior to the origin of the ACL. The posterior horn attaches to the tibial plateau immediately anterior to the posterior cruciate ligament PCL and just posterior to the posterior lateral meniscal attachment. The peripheral margin of the medial meniscus is firmly attached to the joint capsule and to the tibial plateau itself, the latter via the coronary ligament.

The lateral meniscus is semicircular, smaller, and more freely movable than the medial meniscus. Unlike the medial meniscus, it has the same width throughout, with the anterior and posterior horns almost equal in size. The anterior horn of the lateral meniscus attaches immediately lateral to the origin of the ACL .The posterior horn attaches anterior to the PCL and anterior to the root of the posterior horn of the medial meniscus. The posterior horn is also connected to the medial femoral condyle via menisco-femoral ligaments and to the popliteus via popliteo-meniscal fascicles. The lateral meniscus has a loose peripheral attachment to the joint capsule and is normally more mobile than the medial meniscus.

In general, sagittal images optimally show the anterior and posterior horns of the medial and lateral menisci, coronal images help in evaluating the meniscal bodies, and thin-section axial images provide an additional view of the menisci and their free edges.

The medial and lateral menisci, the transverse ligament, and the meniscofemoral ligaments appear homogeneously dark on all pulse sequences.

On sagittal images, the anterior and posterior horns of the menisci appear as isosceles triangles. The posterior horn of the medial meniscus is almost twice the size of the anterior horn. The anterior and posterior horns of the lateral meniscus are more similar in size, with the posterior horn slightly larger than the anterior horn. The posterior horn of either meniscus should never appear smaller than the anterior horn. The more peripheral sagittal images show the bodies of the medial and lateral menisci. On the lateral side, the more central slices take on a “bowtie” configuration because of the smaller

radius of the curvature. Coronal images at the mid-portion of the knee produce the best images of the bodies of both menisci. They appear triangular and slightly larger laterally than medially. On posterior coronal cross-sections, the posterior horns appear as flat bands.[11,12,13,14,15]

BONE AND BONE MARROW

The cortical bone of the distal femur, proximal tibia, and patella is of low signal intensity on all pulse sequences. The signal intensity of the medullary canal, meanwhile, changes in reflection of the changing amounts of hematopoietic and fatty bone marrow with aging; over time, the fatty marrow increases in proportion.

CONCLUSIONS

Thorough understanding of the normal MR anatomy of the knee joint is an essential prerequisite to precise diagnosis of pathological conditions of the joint. MRI imaging due to its excellent soft tissue resolution and multiplanar capability is very useful in understanding complex anatomy of knee joint.

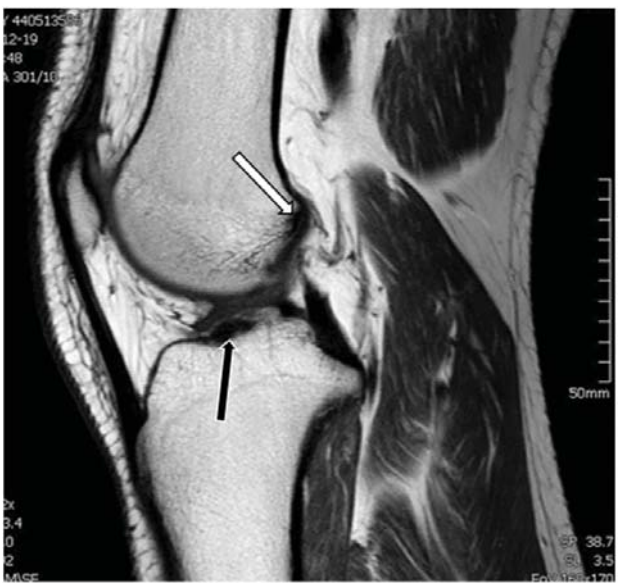

Figure 1. Sagittal T1W image showing the ACL arising from intercondylar area (black arrow) and attaching onposterior part of femoral condyle (white arrow).

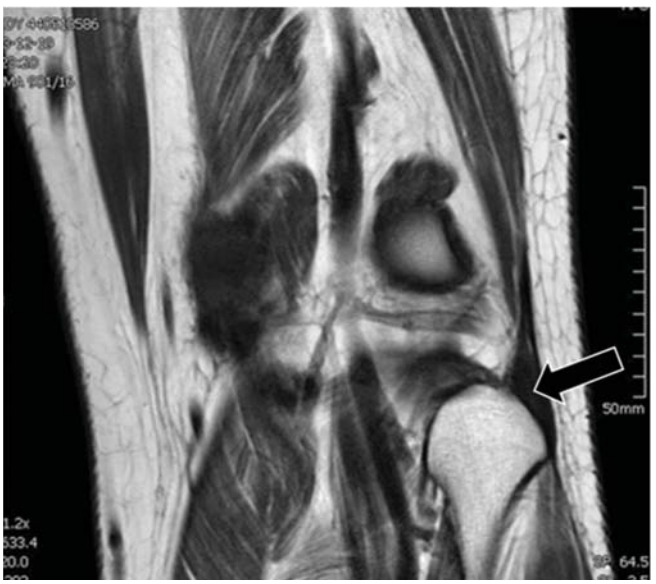

Figure 2. Sagittal T1W image showing the two fiber bundle of ACL. Anteromedial bundle (AMB) is shown by black arrow while posterolateral bundle (PLB) is shown by white arrow. These bundles spread out at the tibial attachment site, but the fibers run in a spiral fashion and may appear as one bundle at the femoral attachment site.

Figure 3. Coronal PDW image showing attachment of ACL on tibia. ACL attaches to the tibia at the site spreading like a fan between the tibial spine and the anterior horn of the medial meniscus (arrows).

Figure 4. Axial T2W image showing ACL flattened against the medial side of lateral femoral condyle.

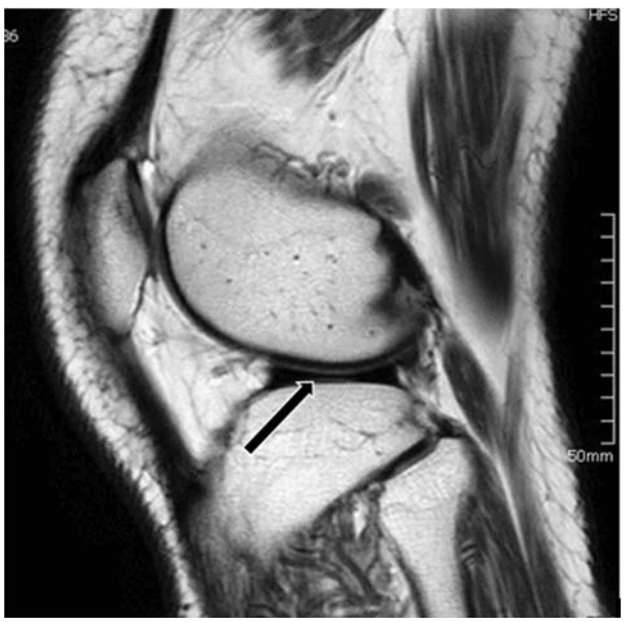

Figure 5. Sagittal T2W image showing the course of PCL. It is seen horizontal at the femoral attachment site and then makes angulation towards tibia as it attaches to posterior intercondylar area of the tibia.

Figure 6. Coronal T1W image showing PCL being inserted into lateral surface of medial femoral condyle.

Figure 7. Coronal T1W image showing MCL extending from medial femoral condyle to the medial tibial plateau.

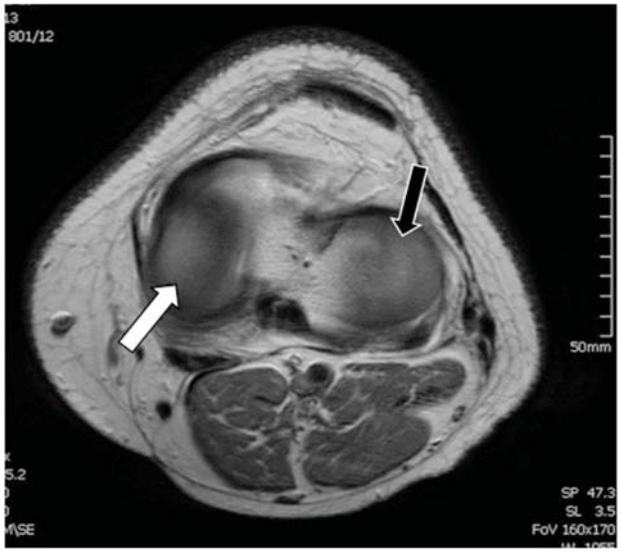

Figure 8. Coronal T1W image showing the three layers of MCL. Layer I (white arrow): thin sheet of fascia. Layer II (black arrow): superficial layer of medial collateral ligament (MCL). Layer III (grey arrow): deep layer of MCL.

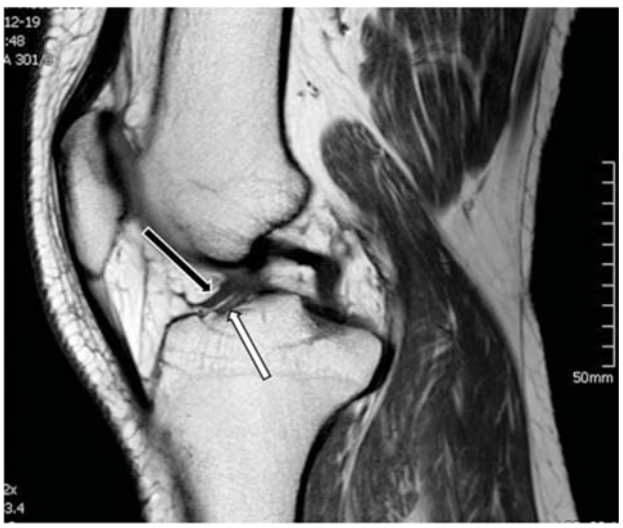

Figure 9. Coronal T1W image to show popliteus muscle and tendon (white arrow) along with lateral collateral ligament (black arrow).

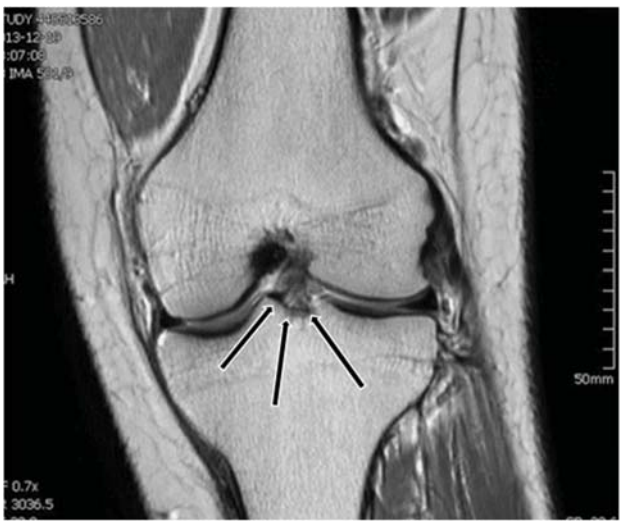

Figure 10. Coronal T1W image showing the conjoined tendon attached to the lateral aspect of fibula head.

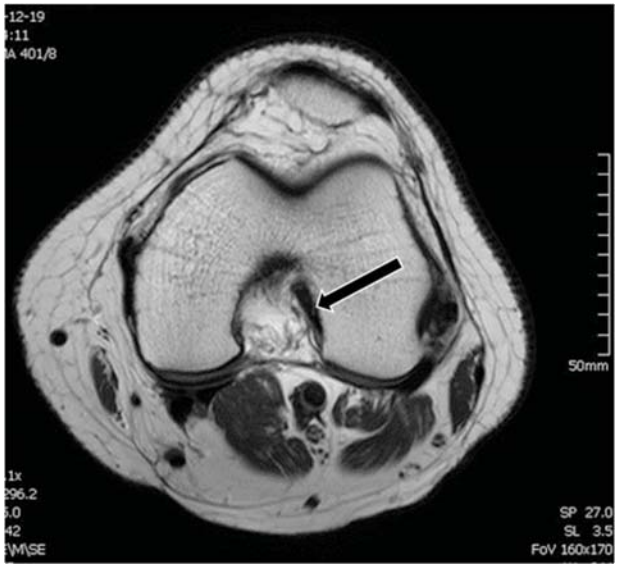

Figure 11. Sagittal T2W image showing the anterior (black arrow) and posterior (white arrow) horns of medial meniscus.

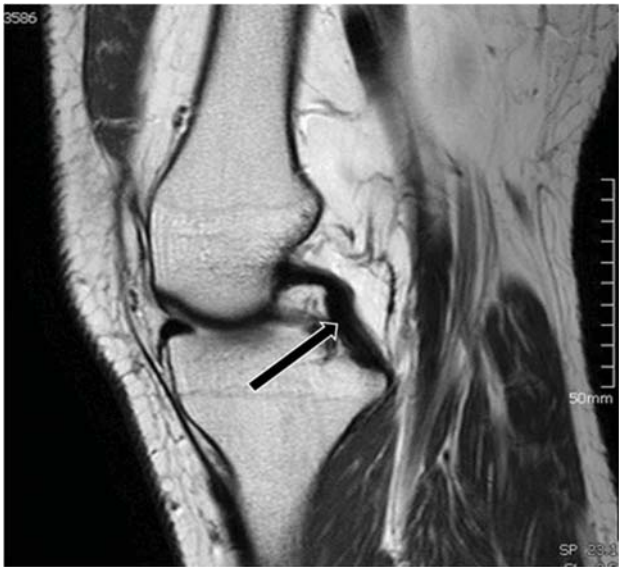

Figure 12. Sagittal T2W image showing the anterior (black arrow) and posterior (white arrow) horn of lateral meniscus.

Figure 13. Sagittal T2W image showing "bowtie" configuration of lateral meniscus.

Figure 14. Coronal PWD image showing medial (white arrow) and lateral (black arrow) menisci.

Figure 15. Coronal T1W image showing the posterior horns of the menisci

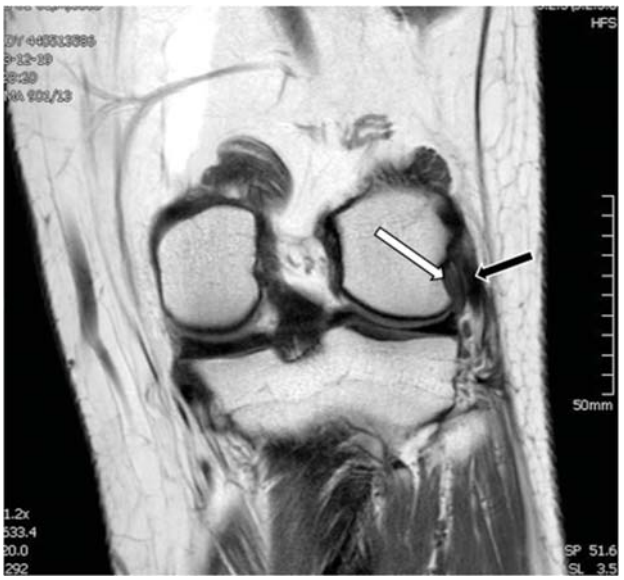

Figure 16. Axial PDW image showing both medial (white arrow) and lateral (black arrow) menisci.

REFERENCES

1. Lauren Shapiro, Ernesto Staroswiecki, Garry Gold. MRI of the Knee: Optimizing 3T Imaging. Semin Roentgenol. 2010 Oct;45(4):238-49. Crossref
2. Helms, Clyde A. Fundamentals of Skeletal Radiology. 4th ed. Philadelphia : Elsevier Saunders;2014. 165-6 p. Crossref
3. Niitsu M, Nakai T, Ikeda K, Tang GY, Yoshioka H, and Itai Y. High-resolution MR imaging of the knee at 3 T.. 1, 2000 Jan, Acta Radiologica;41:84-88. Crossref
4. Oei EH, Nikken JJ, Verstijnen AC, Ginai AZ, Myriam Hunink MG. MR imaging of the Menisci and Cruciate Ligaments: A Systematic Review. Radiology, 2003;226:837-48. Crossref
5. Keith L. Moore, Arthur F. Dalley II, and Anne M. R. Agur. Clinically Oriented Anatomy. 7th ed. Baltimore : Lippincott Williams & Wilkins;2014. 642 p. Crossref
6. Schuenke M, Schulte E, Schumacher U. L.THIEME Atlas of Anatomy - General Anatomy and Musculoskeletal System. Stuttgart. 2010. 390-401 p. Crossref
7. Robinson, Philip. Essential Radiology for Sports Medicine. New York : Springer;2010.1 p. Crossref
8. Berquist, Thomas H. MRI of the Musculoskeletal System, 5th ed. Philadelphia : Lippincott Williams & Wilkins;2006. 304-7 p. Crossref
9. Arthur De Smet, Mark J. Kransdorf, David A. Rubin, Mark W. Anderson, and Mihra Taljanovic. ACR-SSR Practice Guideline for the Performance and Interpretation of Magnetic Resonance Imaging (MRI) of the Knee-Revised 2010 (Resolution 19). American College of Radiology. [Online] October 1, 2010. http://www.acr.org/guidelines. Crossref
10. Clyde A. Helms, Nancy M. Major, Mark W. Anderson, Phoebe A. Kaplan, and Robert Dussault.Musculoskeletal MRI, 2nd ed. Philadelphia : Saunders Elsevier;2009. 353p. Crossref
11. John R. Haaga, Vikram S. Dogra, Michael Forsting, Robert C. Gilkeson, Hyun Kwon Ha, and Murali Sundaram. CT AND MRI of the Whole Body, 5th ed. Philadelphia : MOSBY ELSEVIER;2009. Crossref
12. Mamoru N. Magnetic Resonance Imaging of the Knee.

Daichi Hayashi, Ali Guermazi. translator: Springer;2013. Crossref

13. Vohra S, Arnold G, Doshi S, Marcantonio D. Normal MR Imaging Anatomy of the Knee. 2011;19(3):637-53. Crossref

14. Torsten B. Moeller, and Emil Reif.Pocket Atlas of Sectional Anatomy - Computer Tomography and Magnetic Resonance Imaging, Volume 3. [trans.] Barbara Herzberger. Stuttgart . New York : Thieme, 2007. pp. 200-232. Vol. III. Crossref

15. Adam A, Dixon A, Gillard J, Cornelia M, Schaefer-Prokop C, Grainger R. Grainger & Allison's Diagnostic Radiology - A Textbook of Medical Imaging, 6th ed. Edinburgh : Churchill Livingstone Elsevier;2015. 1079-84 p. Crossref