GOKnee3D – Fully-automated One-button-push High-resolution MRI of the Knee

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Magnetic resonance imaging (MRI) plays a key role in the workup of acute and chronic injuries, pain syndromes, and dysfunction of the knee. While radiographic and computed tomography evaluations provide excellent osseous detail, MRI is most accurate for the detection of bone marrow edema in the setting of radiographically occult bone contusion injuries and osseous stress reactions, non-displaced fractures, acute chondral shear injuries, and degenerative cartilage defects, tears of the collateral and cruciate ligaments, muscle-tendon injuries, and meniscal tears. Also, MRI can diagnose synovitis not only by the presence of a joint effusion, but also by visualizing synovial thickening, edema pattern, and frond-like hypertrophy.

Most MRI protocols of the knee for the assessment of internal derangement include pulse sequences that are tailored for the morphological assessment of anatomic structures, as well as pulse sequences that are tailored to maximize the conspicuity of findings with long T2 constants, such as fluid and edema.

For morphological assessment of the integrity of anatomical structures, intermediate-weighted MR images with echo times around 30 ms and no fat suppression are ideally suited due to their high signal yield, intermediate-to-high fluid signal, and high contrast-to-noise ratios of low signal intensity structures such as menisci, ligaments, and cartilage. The addition of a T1-weighted pulse sequence to the protocol can be beneficial for bone marrow assessment due to their exquisite specificity for fat signal, including osteomyelitis, marrow replacing diseases, and possibly fractures. However, T1-weighted pulse sequences have a lower sensitivity for detecting cartilage defects, ligamentous injuries, and meniscal tears due to absent fluid signal. Structural pulse sequences are often designed with a higher spatial resolution to maximize structural detail and the detection of small abnormalities, such cartilage fissures, and coapted tears.

For the assessment of signal abnormalities, pulse sequences with longer echo times and fat suppression

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3-Dimensional Signal-to-Noise Ratio Maps

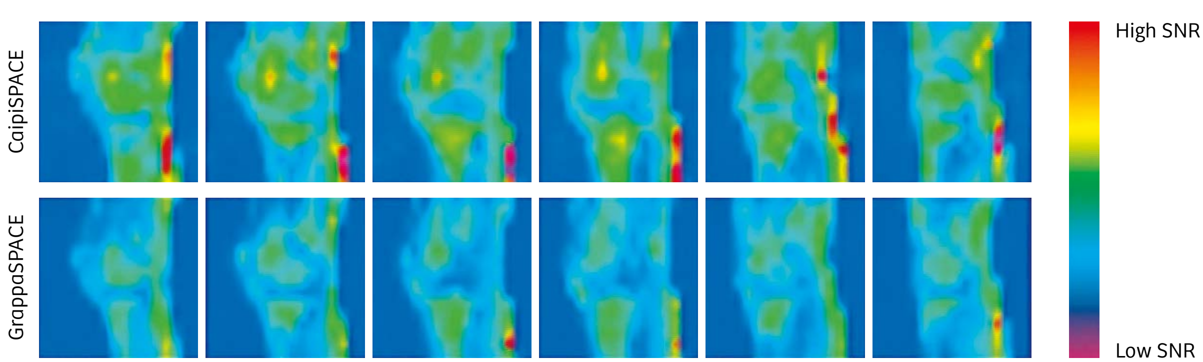


Figure 1:
3-Dimensional Signal-to-Noise Ratio maps illustrate the higher signal yield of CAIPIRINHA-accelerated 3D SPACE over GRAPPA-accelerated 3D SPACE.

510(k) pending. The product is not commercially available. Future availability cannot be guaranteed.

are typically used to increase the conspicuity of findings with long T2 constants, such as joint fluid, collections, and edema. The presence of an edema pattern in bone, ligaments, muscles, and fatty tissues often allows the differentiation of an acute injury or inflammation from chronic remodeling. Abnormally T2 hyperintense areas also have a higher suspicion to be a pain generator. Fast and turbo spin echo (TSE) pulse sequences with effective echo times of 60–70 ms and spectral fat suppression result in exquisite fluid sensitivity. The use of Spectral Attenuated Inversion Recovery (SPAIR) technique, instead of conventional spectral fat suppression can improve the homogeneity of fat suppression across the field-of-view [1]. Alternatively, STIR (Short Tau Inversion Recovery) technique may be used. Fluid sensitive sequences can be designed with less spatial resolution, as it does not interfere with their fluid-sensitivity but can improve efficiency and compensate for the lack of signal from suppressed fat-bound protons.

Two-dimensional (2D) TSE pulse sequences can be acquired with a high in-plane spatial resolution, e.g., with a pixel size of 0.5 x 0.5 mm^2 and less. However, to gain enough MR signal, a slice thickness of 2–4 mm is required, which lowers the effective spatial resolution and results in partial volume effects. The anisotropic voxel size prevents multiplanar reformations and requires the separate acquisition of images in axial, sagittal, and coronal orientation, which can be a time-consuming process and often requires total protocol acquisition times of 20 minutes.

Three dimensional (3D) TSE techniques such as Sampling Perfection with Application optimized Contrast using different flip angle Evolutions (SPACE) yield markedly more MR signal, due to volume-based excitation and use of multiple additional phase-encoding steps in a second direction. Together with the much higher signal yield, 3D data sets allow for the generation of much thinner slices partitions and facilitate 3D MRI with isotropic voxels size.

Figure 2:
Normal left knee of a 37-year-old healthy man. Sagittal isotropic 0.5 mm intermediate-weighted and 0.6 mm T2-SPAIR-weighted 3D CAIPIRINHA SPACE source MR images **(2A, B)** with standard axial **(2C, D)** and coronal **(2E, F)** reformats.

3

AA Scout	IW 3D CAIPIRINHA SPACE	TSFS 3D CAIPIRINHA SPACE
13 sec	4 min 41 sec	4 min 45 sec
Total Scan Time: 9 min 39 sec		

Figure 3:
GOKnee3D protocol for 3T MRI of the knee in under 10 minutes.

Such isotropic data sets with sufficiently small voxel size virtually eliminate partial volume effects and provide an opportunity for the improved display of small anatomic detail. Also, virtually any imaging plane can be reformatted from a single parent dataset (Fig. 1), including standard axial, sagittal, and coronal MR images, as well as oblique and curved planar reformations and 3D volume-rendered MR images.

The two phase-encoding directions of 3D SPACE provide an opportunity for bi-directional acceleration. A 2 x 2 parallel imaging using a Generalized Autocalibrating Partial Parallel Acquisition (GRAPPA) sampling pattern facilitates a 4-fold acceleration without the occurrence of acceleration and aliasing artifacts. As a further development, the use of a shifted Controlled Aliasing In Parallel Imaging Results IN Higher Acceleration (CAIPIRINHA) sampling pattern results in the optimized use of differential coil spatial sensitivities and improved geometry (g) factor performance [2, 3]. When compared to GRAPPA SPACE, CAIRPINIHA SPACE is characterized by increased image quality and 10–20% higher signal-to-noise ratios (Fig. 1). CAIPIRINHA-based 4-fold acceleration substantially reduces the time required for data acquisition and eliminates the need for compromises, including long echo trains, partial Fourier undersampling, and anisotropic data acquisition (Fig. 2) [4–6]. CAIPIRINHA SPACE with integrated anatomical landmark-based AutoAlign Knee technology, which provides automatic field-of-view and slice positioning, builds the foundation for GOKnee3D – a fully automated, one-button-push, high-resolution, 3D isotropic diagnostic knee exam with intermediate- and T2-SPAIR-weighted image contrasts and a total acquisition time of fewer than 10 minutes (Fig. 3).

The development of GOKnee3D adopted a similar strategic approach as earlier GO (Generalized Optimized) strategies [7–9]. The clinical validation study of GOKnee3D included head-to-head comparisons with conventional exams of 100 patients that were scanned at the MAGNETOM Skyra (3T) and 50 patients that were scanned at the MAGNETOM Aera (1.5T) [10]. All patients underwent the 10-minute GOKnee3D exam as well as a high-quality conventional 20-minute 2D exam that included six separately acquired pulse sequences of standard non-fat-suppressed and fat-suppressed clinical contrasts in three orientations. All images were independently evaluated by two board-certified, fellowship-trained musculoskeletal radiologists. The images were assessed for the presence or absence of joint effusion, joint bodies, popliteal cysts, lateral and medial meniscal tears, medial and lateral collateral ligament tears, anterior and posterior cruciate ligament tears, quadriceps and patella tendon tears, cartilage defects, bone marrow edema, and fractures. Additionally, the overall image quality and severity of motion artifact were also evaluated.

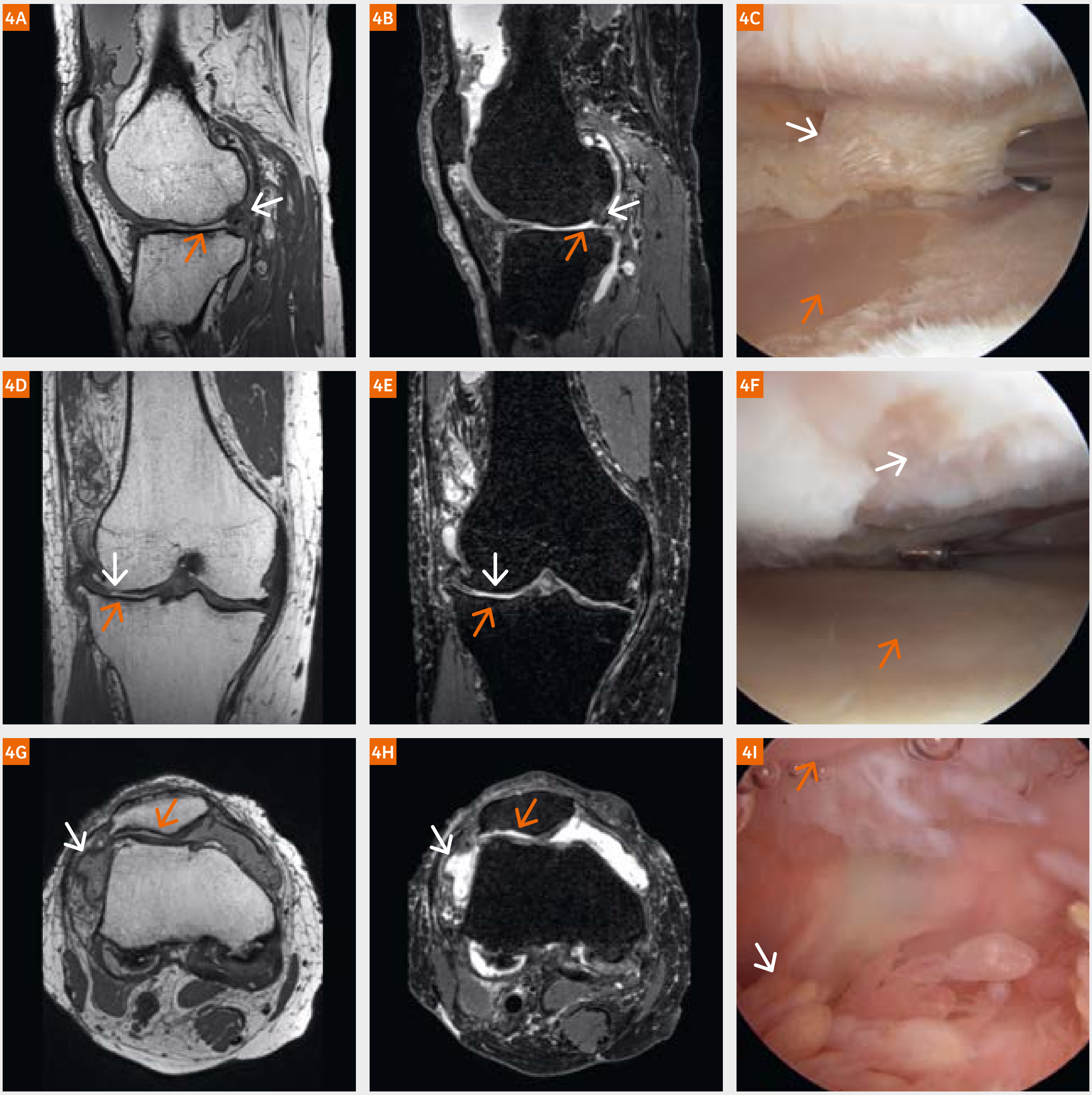
The study results indicate that the images generated by the 10-minute GOKnee3D protocol are at least diagnostically equivalent to the images of a 20-minute 2D TSE standard of reference protocol. There were no significant differences in the diagnosis of abnormal findings between GOKnee3D and the 2D TSE exams at both 1.5T and 3T. For both, 1.5T and 3T GOKnee3D protocols, the inter-reader agreement was consistently higher for the 3D images when compared to the 2D images.

An ongoing study evaluating the diagnostic accuracy of GOKnee3D for the detection of internal derangement in children[1] and adolescents, with arthroscopy as the standard of reference, indicates sensitivities of 83–100% and specificities of 93–100% for the diagnoses of discoid menisci, meniscus tears, ligament injuries, and osteochondritis dissecans lesions [11]. This study is currently being extended to adult patients.

The following clinical cases with surgical correlation illustrate the application of GOKnee3D for the evaluation of internal derangement in adults and children. All images were acquired on a 3T MAGNETOM Skyra MR imaging system (Siemens Healthcare, Erlangen, Germany) and Tx/Rx Knee 15 (QED, Mayfield Village, OH, USA) surface coil.

[1] MR scanning has not been established as safe for imaging fetuses and infants less than two years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures.

Case 1

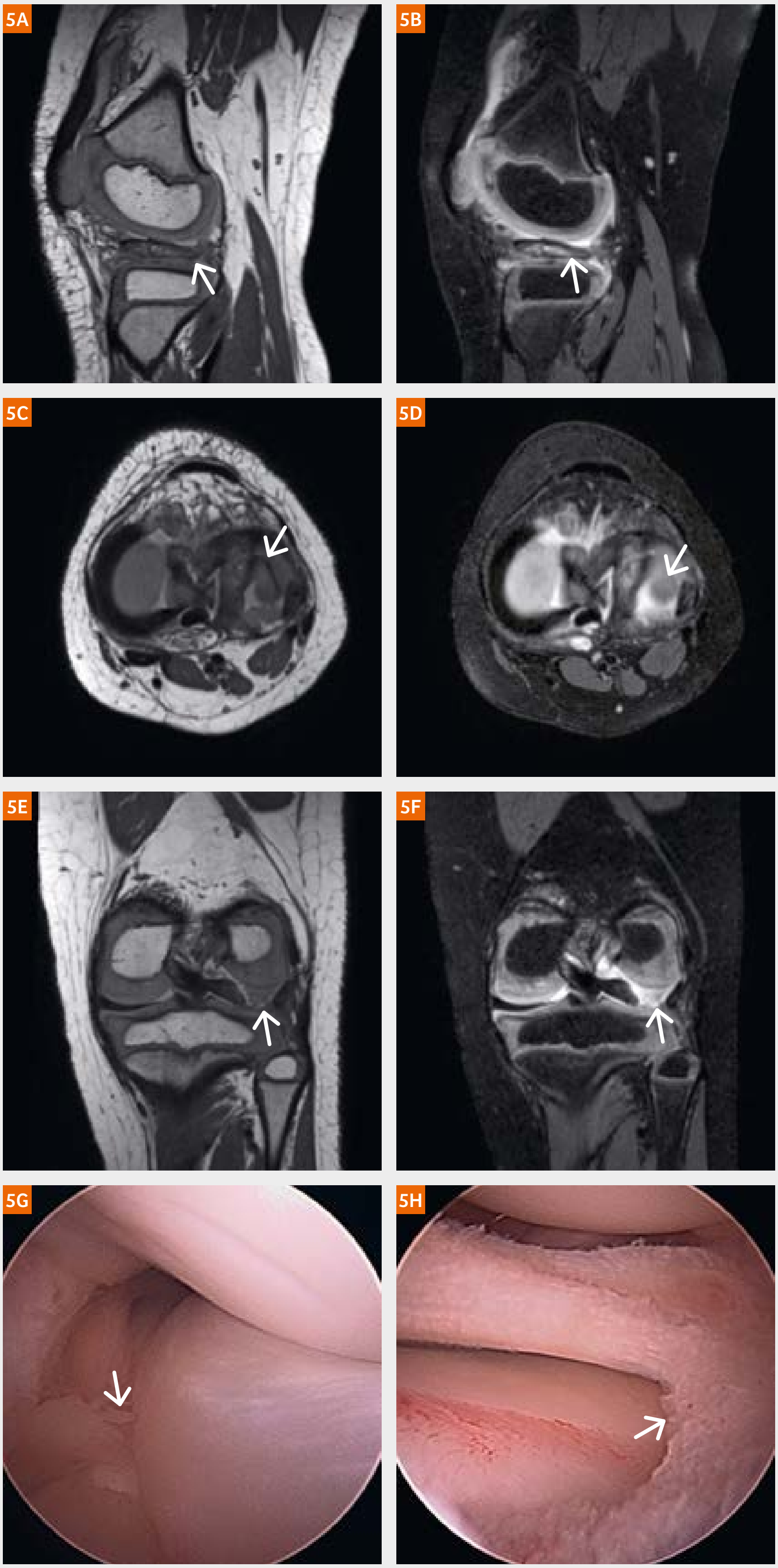


Indication: 60-year-old woman with intermittent pain and swelling of the right knee.

MRI findings: Sagittal, coronal, and axial intermediate-weighted and T2-SPAIR GOKnee3D images demonstrate a degenerative, complex tear of the posterior lateral meniscus (white arrows, **4A and 4B**). There is full-thickness cartilage loss over the lateral femoral condyle and lateral tibia plateau with focal bone-on-bone apposition (orange arrows, **4A and 4B**; white and orange arrows, **4D and 4E**). There is full-thickness cartilage loss of the lateral facet of the patella (orange arrow, **4G and 4H**) and synovitis with frond-like proliferations (white arrow, **4G and 4H**).

Arthroscopy findings: Degenerative, complex, tear of the posterior lateral meniscus (white arrow, **4C**). Full-thickness cartilage defects of the central femur (orange arrow, **4C and 4F**), tibia plateau (white arrow, **4F**), and lateral patella (orange arrow, **8I**) with synovitis (white arrow, **4I**).

Case 2

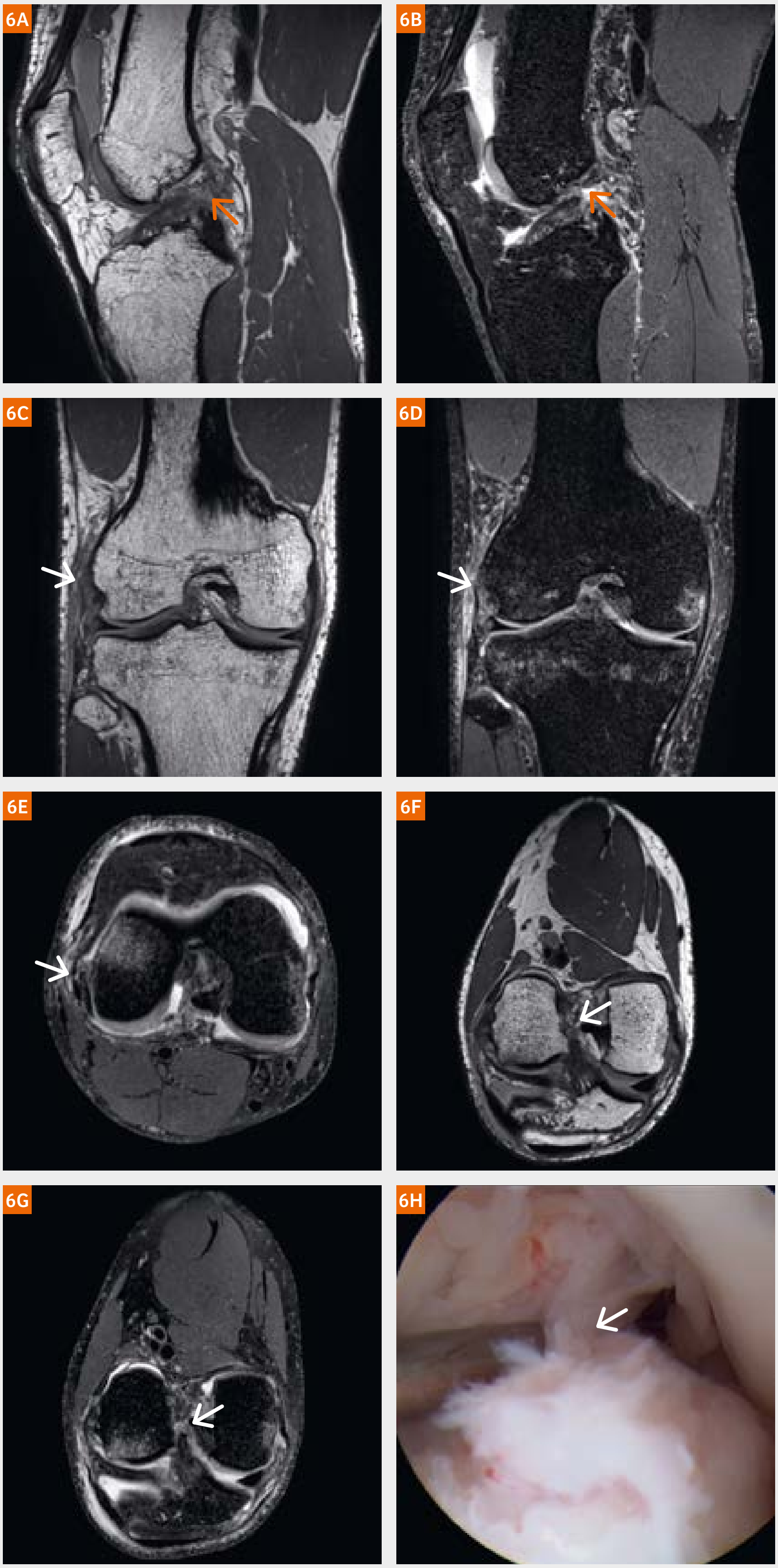


Indication: 4-year-old girl with mild knee pain and locking with motion.

MRI findings: Sagittal, coronal, and axial GOKnee3D images demonstrate a near complete discoid lateral meniscus with a complex tear (arrows). The medial meniscus, anterior and posterior cruciate ligaments, medial and lateral collateral ligaments, and articular cartilage are intact. There is a mild synovitis with small joint effusion.

Arthroscopy findings: Discoid lateral meniscus with a complex tear (arrow, **5G**), which was treated with resection of the tear and saucerization to create the crescent shape of a normal lateral meniscus **(5H)**.

Case 3

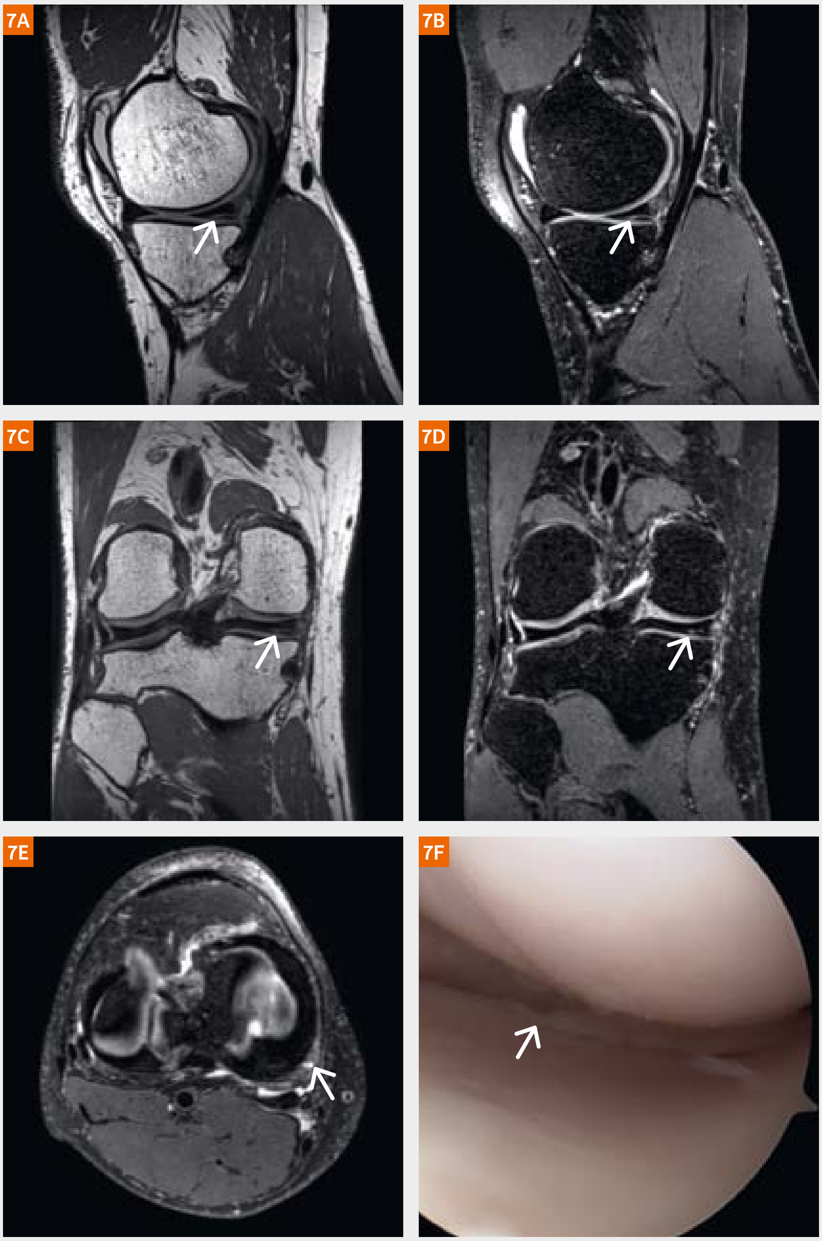


Indication: 30-year-old man with pain, swelling, and instability of the right knee following an American football injury.

MRI findings: Sagittal, coronal, axial and axial oblique GOKnee3D images demonstrate a full-thickness tear of the anterior cruciate ligament near the femoral attachment (arrow, **6A, B, F, G**). Additionally, there is a hemorrhagic joint effusion, a partial thickness tear of the lateral collateral origin (arrow, **6C–E**), and bone contusions of the femur and tibia.

Arthroscopy findings: Full-thickness tear of the anterior cruciate ligament near the femoral attachment (arrow, **6H**).

Case 4



Indication: 52-year-old man with intermittent pain along the medial joint line of the knee.

MRI findings: Sagittal, coronal, and axial intermediate-weighted and T2-SPAIR GOKnee3D images demonstrate a complex, partial depth tear of the peripheral zone 1 of the posterior medial meniscus (arrows, **7A–D**). The meniscal tissue quality appears preserved. Additionally, there are small paramensical cysts at the location of the tear (arrow, **7E**).

Arthroscopy findings: Complex, partial depth tear of the peripheral zone 1 of the posterior medial meniscus (arrow, **7F**).

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Case 5

Indication: 14-year-old boy with anterior knee pain.

MRI findings: Sagittal, coronal, and axial oblique GOKnee3D images demonstrate patella alta alignment, hypoplasia of the trochlea, lateral patellar shift, and a full-thickness cartilage defect (arrows, **8A–D**) of the central patella with subcortical cyst formation and a small area of bone marrow edema pattern. There is a small joint effusion. The lateral and medial meniscus (arrows, **8E**) are intact.

Arthroscopy findings: Patellar chondromalacia with full-thickness cartilage defect (arrow, **8F**).

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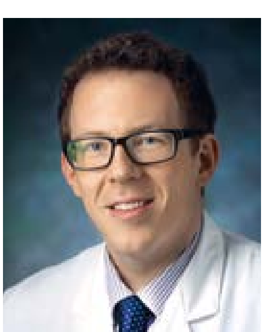
Case 6

Indication: 51-year-old man with intermittent pain and locking of the left knee.

MRI findings: Sagittal and coronal intermediate-weighted and T2-SPAIR GOKnee3D images demonstrate a bucket handle tear of the lateral meniscus (white arrow, **9A–D**). The anterior cruciate ligament (asterisk, **9A–D**) and the posterior cruciate ligament (orange arrow, **9A** and **9B**) are intact.

Arthroscopy findings: Bucket handle tear of the lateral meniscus (arrow, **9F**).



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