Cartilage Imaging of the Knee at 3T: Experiences with Different Sequences on a MAGNETOM Skyra Fit MRI System

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Abstract

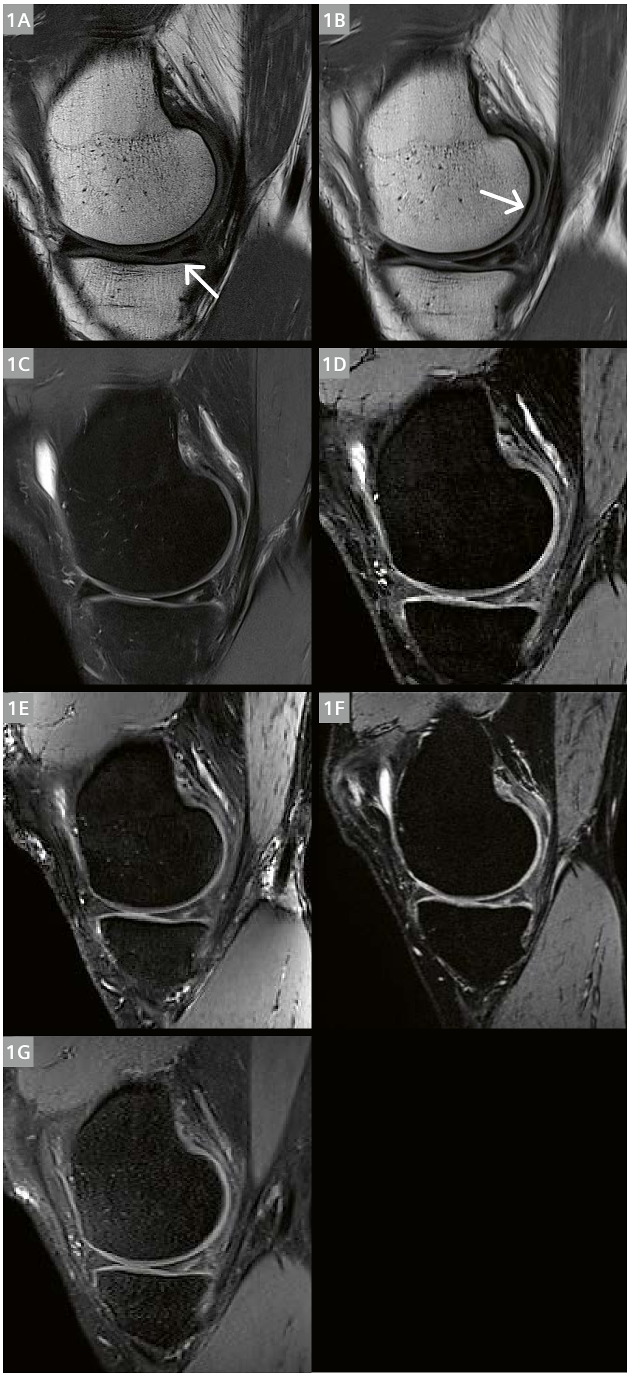
Proton-density-weighted fat-suppressed or intermediately-weighted fat-suppressed turbo spin echo sequences are currently the standard two-dimensional (2D) sequences to delineate the cartilage of the knee. Several three-dimensional (3D) sequences are now available to assess cartilage with isotropic voxels and a reduced scan time thanks to the option of multiplanar reformations. We report here on our experience of cartilage imaging of the knee in clinical daily routine with different sequences on a MAGNETOM Skyra Fit 3-Tesla MRI system.

In order to answer questions on therapy from our clinical partners, we need to have robust and reliable, as well as consistent depiction of articular cartilage. Clinical questions, which need to be answered relate to the extent and depth of cartilage lesions, as well as to the differentiation of cartilaginous from bony components of a lesion and to the lesion's location within the compartments of the knee. To maximize the therapeutic and prognostic relevance of findings from cartilage imaging, radiologists need to be sensitive to often very subtle imaging clues. At the same time, we need to be aware of the limitations of our methods. Any displaced fragments, concomitant meniscal, ligamentous, and/or degenerative lesions that may be present need to be identified. To date, MRI is the workhorse of cartilage imaging and is largely based on moderately T2-weighted or proton-density (PD)-weighted fat-suppressed turbo spin echo (TSE) sequences [1, 2]. Direct MR and CT arthrography are the gold standard for evaluating thin cartilage layers, for instance to delineate the integrity of osteochondral lesions of the ankle joint [3]. Recent advances in coil and MR sequence design, increased availability of 3T MRI systems, and more and more sophisticated acceleration techniques allow for better spatial resolution and more robust image contrast with acceptable scan times. Recent advances in MRI include 3D isotropic joint imaging, which deliver higher signal-to-noise ratios of the cartilage in the ankle joint and fewer partial volume artifacts, for example, when compared with standard 2D sequences [3].

Imaging-based analysis of articular cartilage and its defects, as well as the radiologist who performs it, have to help answer the increasingly specific clinical questions that result from the growing experience with cartilage-dedicated therapies. Local aspects and topographic distribution of bone marrow edema patterns, careful analysis of the cartilage surface and of the subchondral plate, as well as the patient's clinical and biomechanical context are key to image analysis. Formal grading is helpful to communicate imaging findings, but is not sufficient for a comprehensive analysis [4]. It is more important to use the same language as the referring clinician and to have regular face-to-face case discussions; ideally before and after cartilage surgery or arthroscopy. When planning therapy, it is essential to assess the stability of a pure cartilage lesion or an osteochondral lesion. While MR imaging is helpful in this regard, it can be challenging and requires consideration of the arthroscopic and histologic perspective. This is why close communication with the orthopedic and trauma surgeon is critical for quality control in radiology reporting. In the following, we report on cartilage imaging findings using a MAGNETOM Skyra Fit system relevant for lesion analysis based on our experience in clinical routine.

At our MAGNETOM Skyra Fit system (software version *syngo* MR E11C), we use the following protocol for cartilage imaging of the knee with a dedicated 15-channel knee coil from Siemens Healthineers:

Protocol	Acquisition Parameters	TA
Localizer		0:27 min
Sag T1 TSE	Voxel 0.3 x 0.3 x 3 mm, FOV 170 mm, TR 560 ms, TE 12 ms	3:38 min
Sag PD TSE fs	Voxel 0.3 x 0.3 x 3 mm, FOV 170 mm, TR 5030 ms, TE 31 ms	3:43 min
Cor PD TSE fs	Voxel 0.4 x 0.4 x 3 mm, FOV 170 mm, TR 3000 ms, TE 26 ms	3:38 min
Ax PD TSE fs	Voxel 0.4 x 0.4 x 2.5 mm, FOV 140 mm, TR 4550 ms, TE 27 ms	3:58 min
DESS 3D	Voxel 0.6 x 0.6 x 0.6 mm, FOV 150 mm, TR 14.1 ms, TE 5 ms	5:30 min

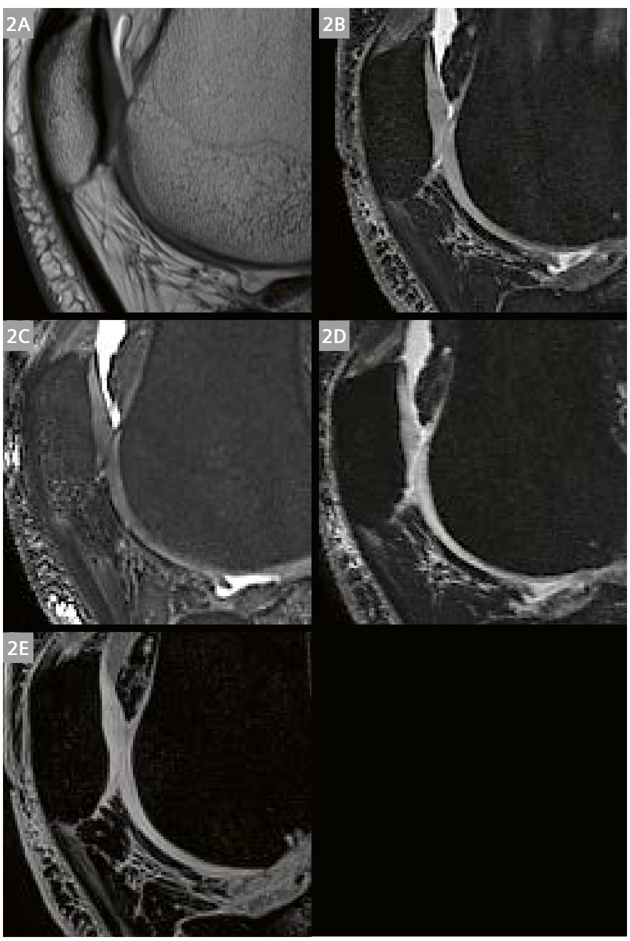


1 35-year-old patient with chronic knee pain. MRI shows a horizontal tear in the medial meniscus (arrow). The cartilage is normal. **(1A)** Sagittal 2D T1-weighted turbo spin echo (TSE), **(1B)** sagittal 2D proton density (PD)-weighted TSE, **(1C)** sagittal 2D PD fat-saturated (fs) TSE – all with 3 mm slice thickness. **(1D)** 3D T2 DESS in sagittal reformation with isotropic 0.6 mm^3 voxel size, **(1E)** 3D T2 TrueFiSP (TR/TE 7.78/3.37 ms, TA 6:25 min) in sagittal reformation with isotropic 0.6 mm^3 voxel size, **(1F)** 3D T2* MEDIC fs (TR/TE 44/16 ms, TA 7:44 min) in sagittal reformation with isotropic 0.6 mm^3 voxel size, **(1G)** 3D T1 SPACE fs (TR/TE 700/11 ms, TA 4:58 min) in sagittal reformation with isotropic 0.6 mm^3 voxel size. The meniscal tear is clearly visible in all 3D sequences.

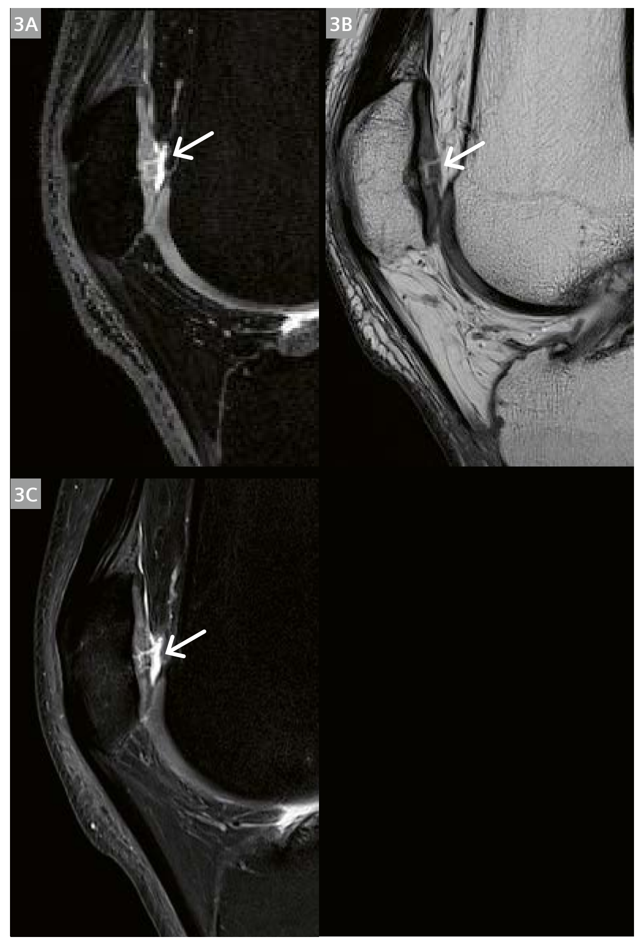
In our experience, when using conventional 2D sequences for the assessment of morphology with high in plane resolution, the following sequence-specific findings can be observed in the cartilage of a normal knee (Fig. 1). When using a T1-weighted sequence, there is little contrast between cartilage to synovial fluid (Fig. 1A). A PD-weighted TSE sequence shows better contrast between cartilage and the joint fluid but displays chemical-shift artifacts (arrow) that limit the conspicuity of the subchondral bone layer. It also has a low dynamic range regarding the cartilage (Fig. 1B). We prefer to use PD TSE sequences with spectral fat suppression (fs) to achieve suppression of the chemical-shift artifacts (compare the cartilage – subchondral bone transition in Fig. 1B with Fig. 1C) and a higher contrast range due to the spectral fat suppression pulse (Fig. 1C). A similar image impression compared with the PD fs TSE is provided by the 3D DESS (double echo steady state) sequence (Fig. 1D), which enables an isotropic voxel size of 0.6 mm^3 and secondary multiplanar reformations. Likewise, a 3D TrueFISP (true fast imaging with steady state precession) sequence achieves good contrast between cartilage and bone (Fig. 1E). Other 3D sequences for cartilage imaging of the knee joints are the MEDIC (multi-echo data image combination) sequence (Fig. 1F) and the SPACE (sampling perfection with application-optimized contrasts using different flip-angle evolution) sequence (Fig. 1G). A variant of the 3D TSE sequence, the SPACE sequence can be used with different weightings such as PD or T1. SPACE PD fs seems to be a good compromise between known contrast and signal behavior of 2D TSE sequences, and high in-plane and through-plane resolution [5]. Gradient-echo sequences such as FLASH (fast low-angle shot) yield a high cartilage signal (Fig. 2), but these sequences have been shown to be inferior regarding the detection of cartilage lesions when compared with PD fs TSE sequences [6]. A 3D sequence gives us a volume dataset; because of the isotropic voxels, we then have the potential to perform secondary reconstructions in any plane (e.g., along the anterior cruciate ligament). With just one or two 3D sequences instead of the entire knee protocol (usually consisting of at least four 2D sequences) and a compliant patient who does not move significantly, the measurement time can be greatly reduced while retaining high resolution. Moreover, the diagnostic performance of 3D MRI has shown statistically significant improvements over the last three decades: Several studies have demonstrated that 3D and 2D sequences have comparable performance in cartilage imaging of the knee (Figs. 3, 4), including studies with arthroscopic correlation [7].

Furthermore, 3D multiplanar reformation has been associated with higher specificity compared with conventional axial, sagittal, and coronal 2D MRI planes in a recent meta-analysis for depicting cartilage defects in the knee [7]. Currently, 3D MRI provides diagnostic performance comparable to 2D MRI with improvements achieved by using 3T field strength, 3D turbo (TSE), or fast spin echo (FSE) sequences, and multiplanar reformation (MPR) [7, 8].

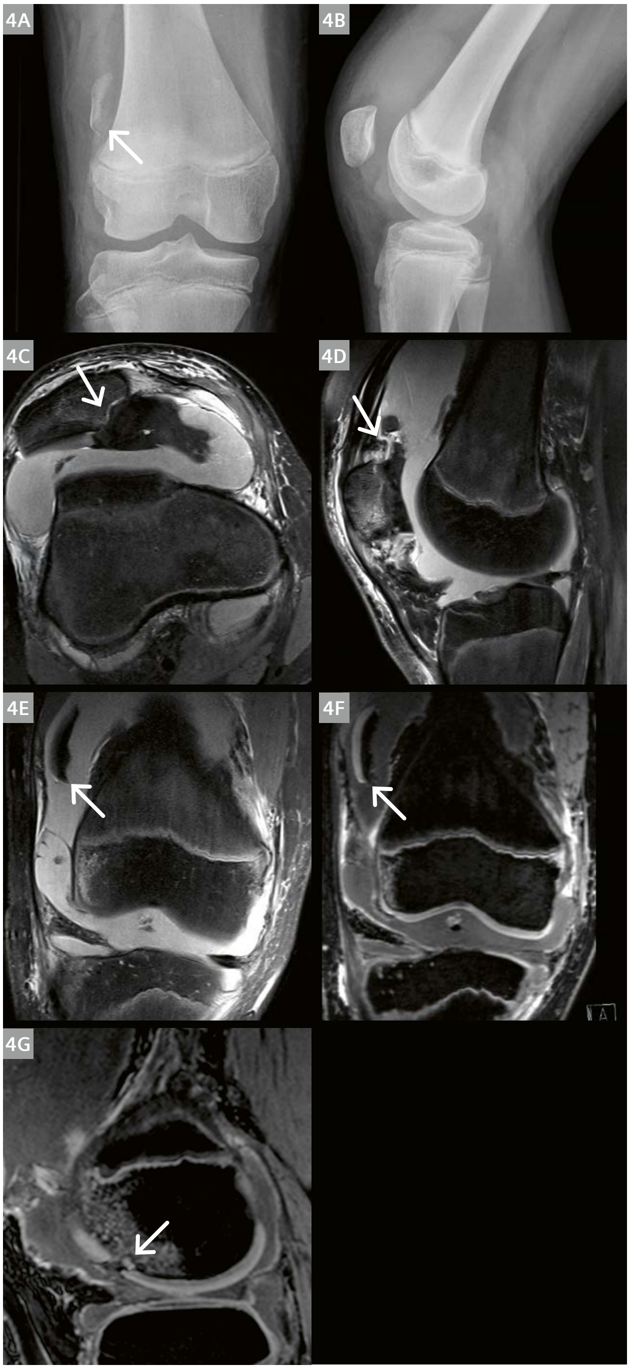
In conclusion, excellent morphological imaging of knee cartilage is now possible using 3T MRI and dedicated coil technology, allowing for the detection of subtle cartilage pathologies. Besides the standard 2D sequences, a multitude of 3D sequences are available for high-resolution cartilage imaging. In addition, the potential of obtaining thinner slices with a 3D sequence enables better detection of smaller lesions. This option may be chosen on an individual basis, such as in the case of a discrepancy between 2D results and clinical symptoms. In such situations, we recommend the use of an additional 3D sequence. As abundant as current developments in clinical routine cartilage imaging may be, the radiologist must carefully select the approach best suited to answering the clinical question at hand.



2 Comparison of different sequences for assessing the retropatellar cartilage. **(2A)** 2D PD TSE with 3 mm slice thickness, **(2B)** 3D T2 DESS in sagittal reformation with isotropic 0.6 mm³ voxel size, **(2C)** 3D T2 TrueFiSP in sagittal reformation with isotropic 0.6 mm³ voxel size, **(2D)** 3D T2* MEDIC fs in sagittal reformation with isotropic 0.6 mm³ voxel size, and **(2E)** T1-weighted VIBE (volumetric interpolated breath-hold examination) sequence (TR/TE 11.7/5.38 ms, TA 5:38 min) in sagittal reformation with isotropic 0.6 mm³ voxel size.



3 37-year-old patient with knee joint distortion and clinically suspected meniscal lesion. **(3A)** Sagittal 3D T2 DESS with isotropic 0.6 mm³ voxel size, **(3B)** sagittal T2-weighted TSE with 2.5 mm slice thickness (TR/TE 3100/66 ms, TA 3:04 min), and **(3C)** sagittal PD fs TSE with 3 mm slice thickness. All sequences demonstrate the retropatellar chondromalacia with deep tears and a non-displaced flap (arrows).



4 13-year-old patient with knee joint distortion and swelling with pain. Radiographs in anteroposterior and lateral projections **(4A, B)**. There was likely trauma to the knee one year prior. Now, the trauma surgeon wants to know whether this displaced fragment is an old flake (arrow). PD TSE fs axial **(4C)** and sagittal **(4D)** sequences show the typical condition after lateral patellar luxation with an osteochondral flake fracture (arrows) and a large hemorrhagic joint effusion. The contrast between bone and cartilage of the osteochondral flake (arrows) is much lower on the coronal standard PD TSE fs **(4E)** compared with the T2 3D DESS (coronal **(4F)** and sagittal reformations **(4G)**). The sagittal DESS also demonstrates additional cartilage damage at the contusion zone of the lateral femoral condyle (arrow).

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