One Sequence, Multiple Contrasts: Toward a Simplified Knee MRI Protocol with 3D PD TSE nDixon

Romain Gillet, Fatma Boubaker, Pedro Augusto Gondim Teixeira, Alain Blum

Service d'Imagerie Guilloz, Hôpital Central — CHRU Nancy, France

1. Introduction

Magnetic resonance imaging (MRI) of the knee remains one of the most frequently performed musculoskeletal examinations worldwide. Despite major advances in acquisition acceleration, routine protocols still rely on multiple two-dimensional (2D) sequences acquired in different planes and contrasts. A typical examination combines several proton density (PD) fat-suppressed sequences with a dedicated T1-weighted acquisition for bone marrow assessment, resulting in scan times that frequently exceed 10 minutes.

Reducing examination time while maintaining diagnostic confidence has become a major objective in musculoskeletal MRI. Beyond improving patient comfort, shorter protocols increase scanner throughput, reduce the likelihood of motion-related image degradation, and improve access to MRI.

Recent developments in isotropic three-dimensional turbo spin-echo (3D TSE) imaging have substantially changed this landscape. Modern volumetric acquisitions now provide image contrast comparable to conventional 2D TSE imaging while enabling high-quality multiplanar reformations from a single dataset. Combined with advances in deep-learning reconstruction, image quality and spatial resolution continue to improve while acquisition times decrease [1].

At the same time, Dixon fat–water separation has emerged as an attractive alternative to conventional spectral fat suppression. In addition to providing homogeneous fat suppression, Dixon reconstruction simultaneously generates water-only, fat-only, in-phase, and opposed-phase images from a single acquisition, thereby expanding the available diagnostic information without prolonging scan time [2].

Over the past decade, Siemens Healthineers has promoted this evolution through concepts such as GOKnee3D, demonstrating that comprehensive knee assessment can be achieved using a limited number of isotropic 3D acquisitions. The next logical step is to move beyond replacing individual 2D sequences with several volumetric acquisitions and instead perform a complete routine knee MRI examination using a single isotropic dataset [3].

The 3D PD TSE nDixon sequence[1] represents this new approach by combining isotropic 3D imaging, Dixon fat–water separation, and deep-learning reconstruction into a single comprehensive acquisition.

[1] *Work in progress. The application is currently under development and is not for sale in the U.S. and in other countries. Its future availability cannot be ensured.*

2. The concept: Combining 3D imaging and Dixon reconstruction

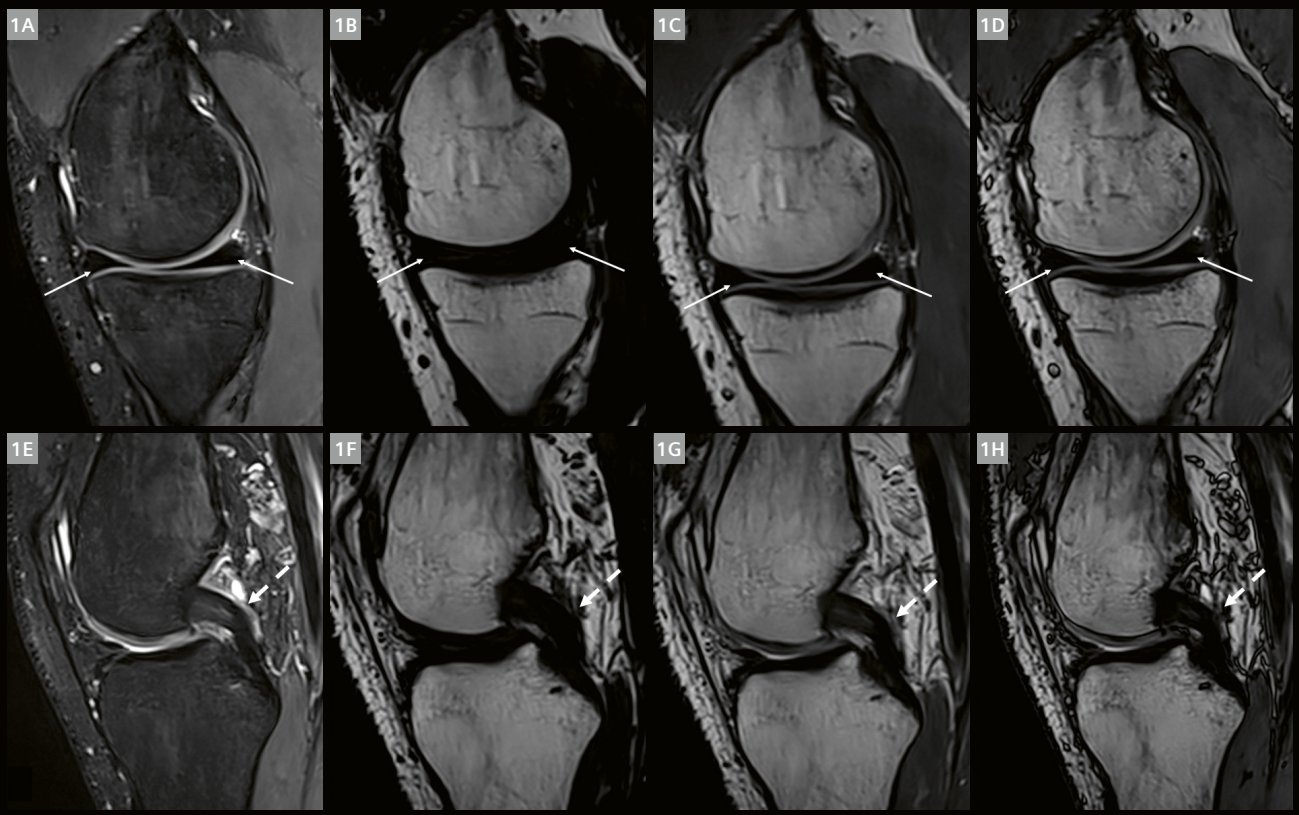
The 3D PD TSE nDixon sequence is acquired in less than six minutes and combines three complementary technologies: isotropic 3D proton-density turbo spin-echo imaging, Dixon fat–water separation, and deep-learning based image reconstruction.

Unlike conventional 3D fat-suppressed TSE sequences that rely on spectral attenuated inversion recovery (SPAIR), Dixon-based reconstruction performs intrinsic fat–water separation and is considerably less sensitive to B0 field inhomogeneities. This advantage is particularly relevant in peripheral musculoskeletal imaging, where complex anatomy and off-center positioning frequently compromise conventional fat suppression.

From a single acquisition, Dixon reconstruction simultaneously provides water-only images equivalent to conventional PD fat-suppressed imaging together with fat-only, in-phase, and opposed-phase reconstructions. Multiple clinically useful image contrasts are therefore generated without increasing acquisition time.

The availability of fat-only images is particularly valuable because they reproduce much of the information traditionally obtained from a dedicated T1-weighted sequence. Bone marrow composition, fatty replacement, marrow reconversion, incidental marrow lesions, fractures, and many bone abnormalities can therefore be evaluated without requiring an additional acquisition [4]. Similar concepts have already been successfully implemented in other musculoskeletal applications, including sacroiliac joint imaging [5].

Together, isotropic imaging and Dixon reconstruction create the possibility of performing a comprehensive routine knee examination using a single volumetric acquisition (Fig. 1).



1 **Representative normal knee MRI obtained with the 3D PD TSE nDixon sequence.**[1] Images demonstrate the anterior and posterior horns of the medial meniscus (solid white arrows; **1A–1D**) and the posterior cruciate ligament (dotted white arrow; **1E–1H**). **(1A, 1E)** Water-only images; **(1B, 1F)** fat-only images; **(1C, 1G)** in-phase images; and **(1D, 1H)** opposed-phase images.

3. Clinical validation

We prospectively evaluated this concept by comparing a single 3D PD TSE nDixon acquisition with a conventional high-resolution knee MRI protocol consisting of four separate 2D TSE sequences, including a dedicated T1-weighted acquisition [3].

The conventional protocol required 12 minutes 6 seconds, whereas the complete 3D PD TSE nDixon examination required only 5 minutes 55 seconds, corresponding to an approximately 50% reduction in acquisition time.

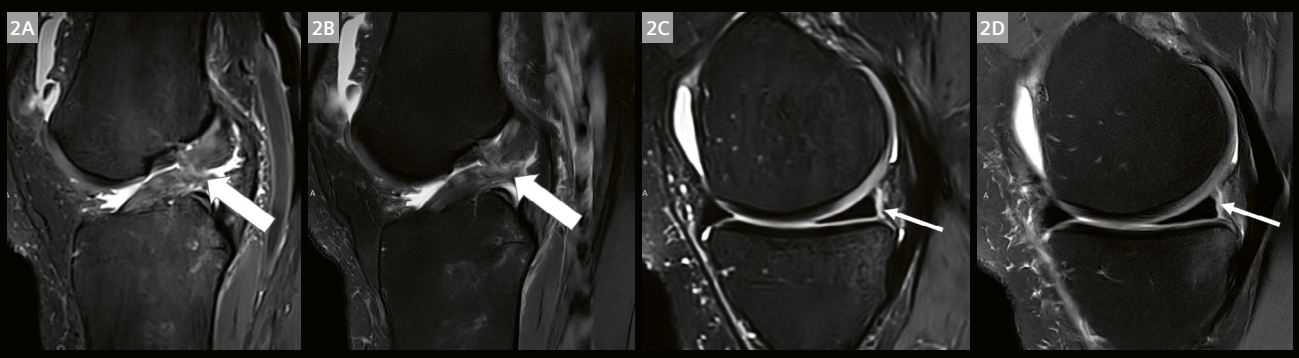
Despite this substantial reduction, diagnostic performance remained comparable for the abnormalities most frequently encountered in daily practice, including meniscal tears, anterior cruciate ligament injuries (Fig. 2), collateral ligament injuries, fractures (Fig. 3), and bone marrow edema. No significant differences in diagnostic accuracy were observed between the two approaches.

The isotropic nature of the dataset also enabled high-quality multiplanar reformations tailored to the anatomy of interest, facilitating the evaluation of complex lesions such as radial meniscal tears and ramp lesions while reducing partial-volume effects (Fig. 4). This also resulted in better interobserver agreement.

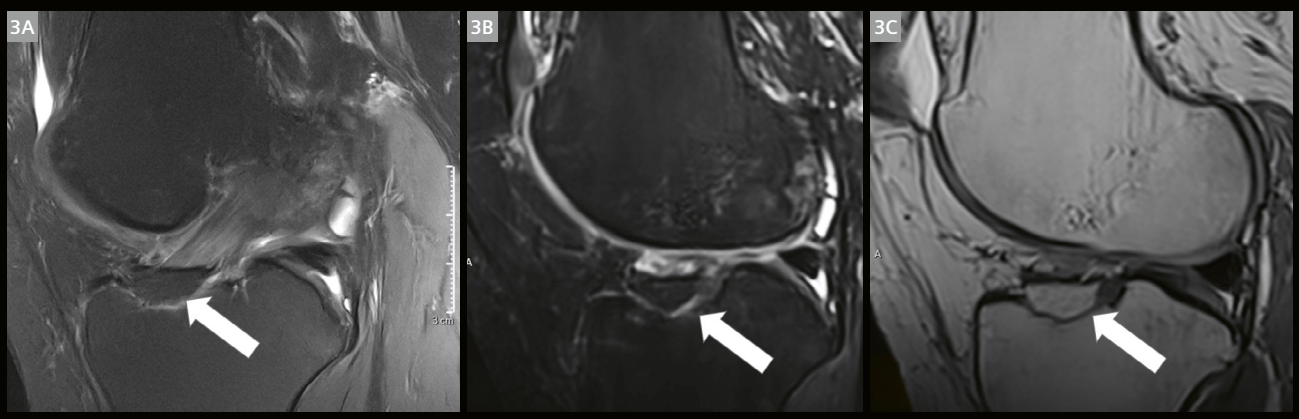
4. Why Dixon changes the workflow

Beyond improving fat suppression, Dixon fundamentally changes the way routine musculoskeletal MRI examinations are interpreted: First, fat suppression is generally more homogeneous and less sensitive to B0 field inhomogeneities than conventional spectral fat-saturation techniques. Second, water-only and fat-only images are generated simultaneously from the same acquisition. In routine knee MRI, radiologists no longer need to alternate between PD fat-suppressed and T1-weighted sequences to assess bone marrow. Both types of information are immediately available within the same volumetric dataset.

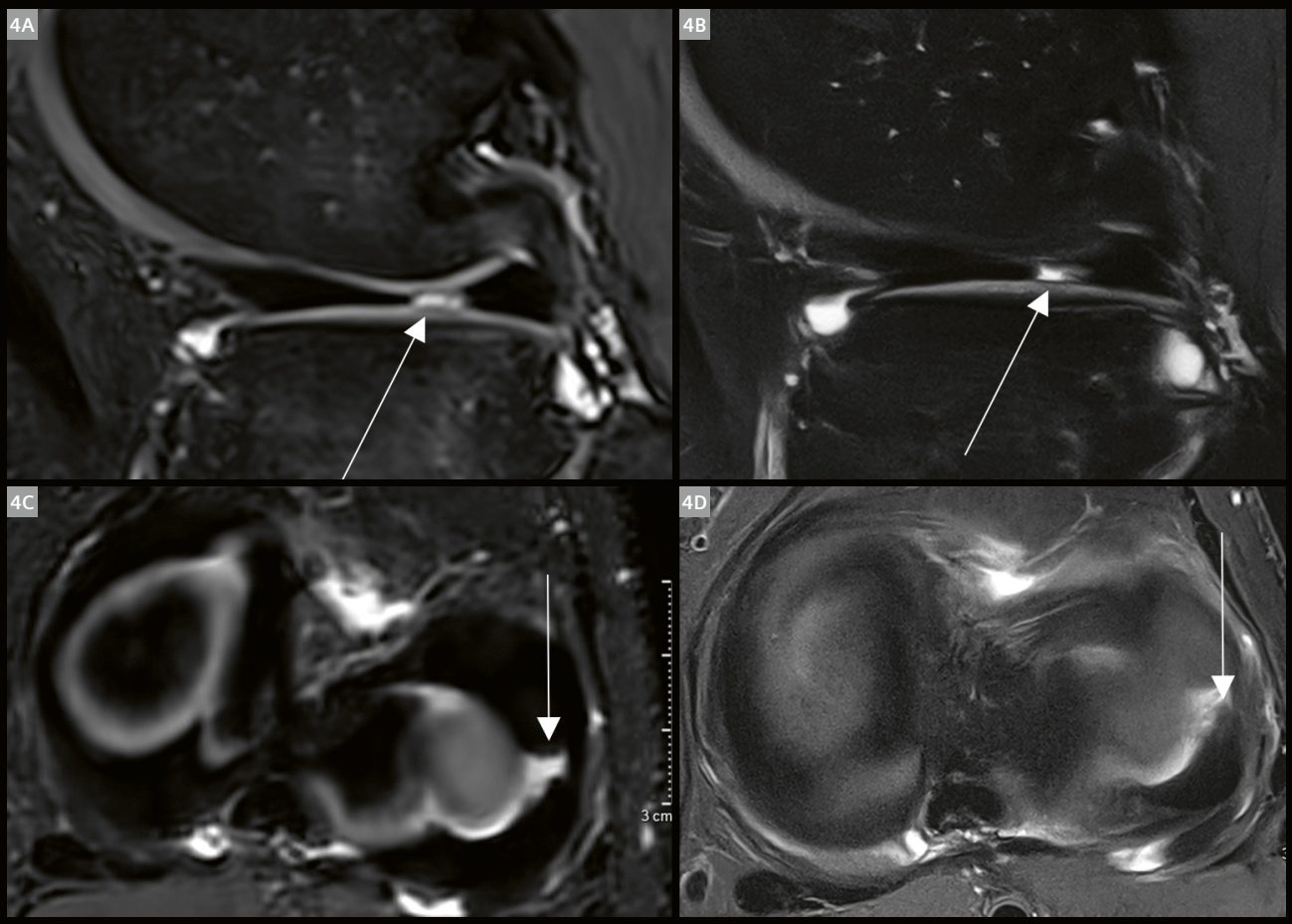
This simplified workflow is particularly valuable when evaluating bone marrow edema, stress injuries, marrow reconversion, osteonecrosis, incidental marrow abnormalities, and focal bone lesions (Fig. 5). Beyond the knee,



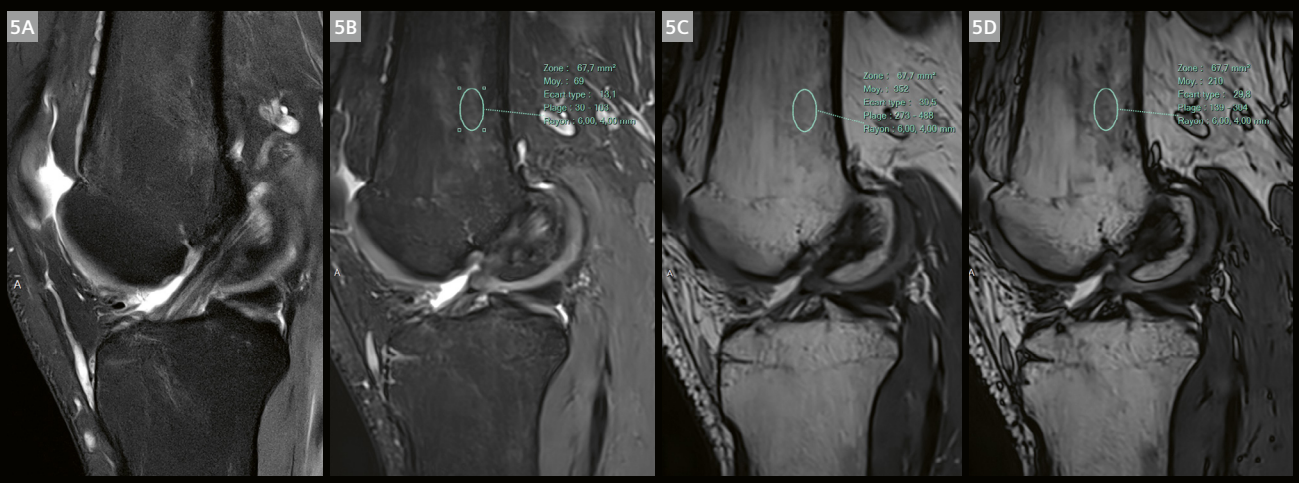
2 **Comparison between 3D PD TSE nDixon and conventional MRI**. Anterior cruciate ligament tear (thick white arrow; **2A, 2B**) and ramp lesion of the medial meniscus (white arrow; **2C, 2D**). **(2A, 2C)** Water-only images from the 3D PD TSE nDixon acquisition; **(2B, 2D)** corresponding conventional high-resolution fat-suppressed PD TSE images.



3 **Comparison between 3D PD TSE nDixon and conventional MRI in a patient with an anterior cruciate ligament enthesis avulsion fracture (thick white arrow). (3A)** Conventional high-resolution fat-suppressed PD TSE image. **(3B)** Water-only image from the 3D PD TSE nDixon acquisition. **(3C)** Fat-only image from the 3D PD TSE nDixon acquisition.



4 **Comparison between conventional MRI and 3D PD TSE nDixon in a patient with a radial tear of the lateral meniscus (white arrow). (4A, 4C)** Water-only images from the 3D PD TSE nDixon acquisition; **(4B, 4D)** corresponding conventional high-resolution fat-suppressed PD TSE images.



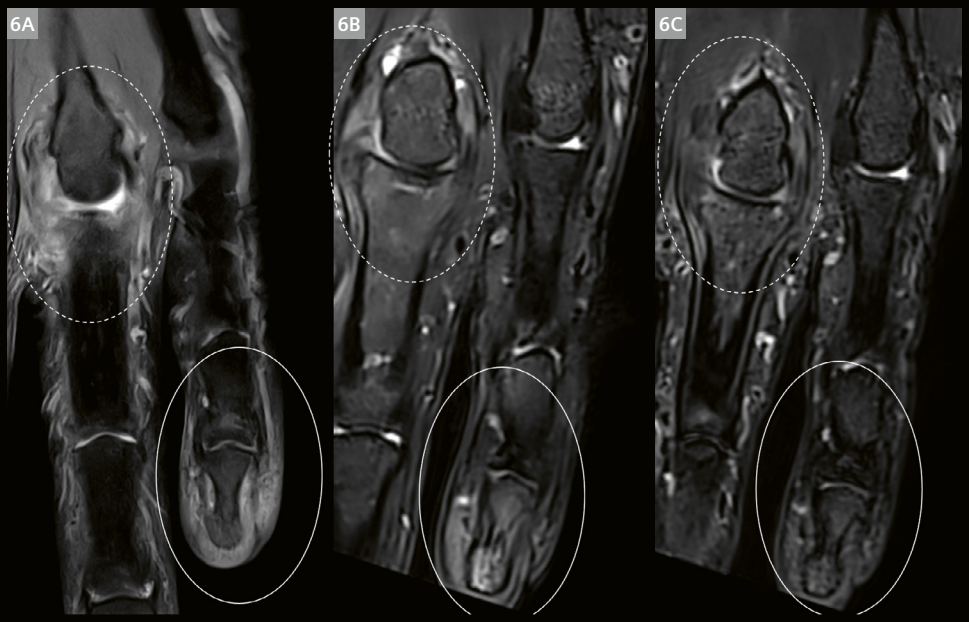
5 **Benign red marrow hyperplasia.** The lesion is visible on the conventional high-resolution fat-suppressed PD TSE image **(5A)** and on the water-only image from the 3D PD TSE nDixon acquisition **(5B)**. The in-phase **(5C)** and opposed-phase **(5D)** reconstructions demonstrate signal loss on the opposed-phase image, consistent with benign marrow hyperplasia.

similar advantages have already been demonstrated in other anatomical regions [4–7].

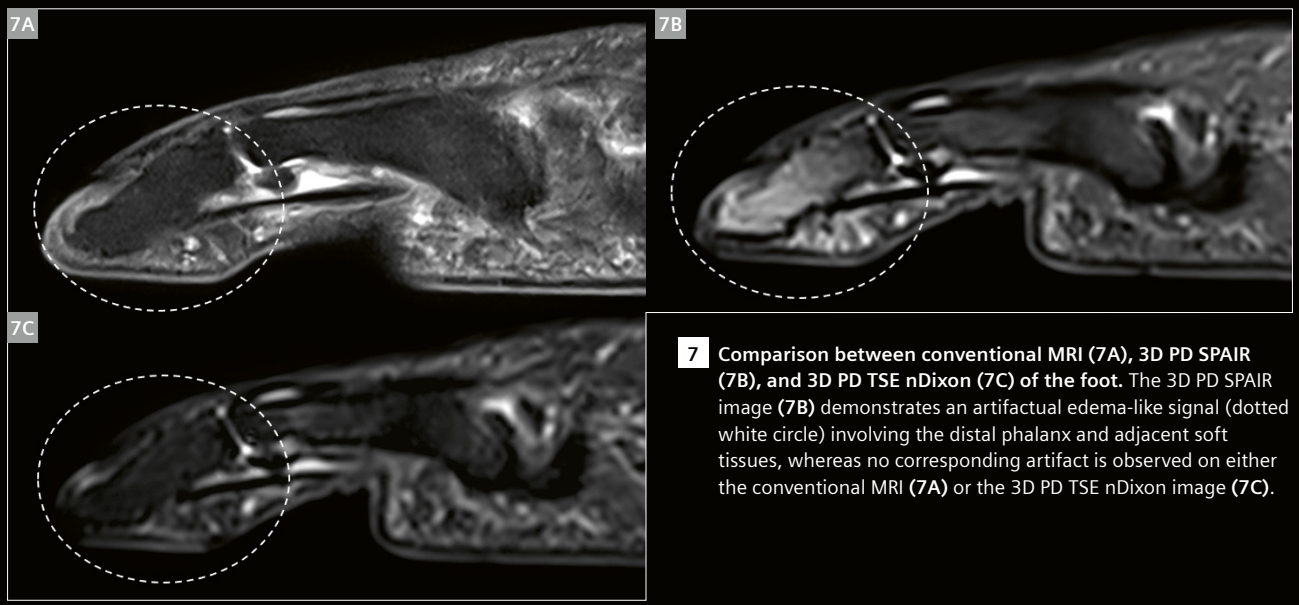
5. Motion robustness: An additional practical advantage

Although motion robustness is not an intrinsic property of the sequence itself, replacing multiple conventional acquisitions with a single volumetric dataset substantially reduces opportunities for patient movement during the examination.

In everyday practice, motion artifacts frequently occur toward the end of MRI examinations, particularly in patients with acute trauma or significant pain. By shortening the overall examination and eliminating repeated repositioning between sequences, the single-acquisition approach naturally decreases the likelihood of motion-related image degradation. This benefit may be particularly relevant for pediatric patients, elderly individuals, and patients who have difficulty remaining still during prolonged examinations.



6 Comparison between conventional MRI (6A), 3D PD SPAIR (6B), and 3D PD TSE nDixon (6C) in a patient with a traumatic capsular injury of the fourth metacarpophalangeal joint (white arrow). The capsular lesion is well depicted on all three sequences. However, spurious edema-like signal (white circle) involving the distal phalanx and adjacent soft tissues is present on the 3D PD SPAIR image **(6B)**, while a similar artifact is visible in the surrounding soft tissues on the conventional MRI **(6A)**. No such abnormality is observed on the 3D PD TSE nDixon image **(6C)**.



7 Comparison between conventional MRI (7A), 3D PD SPAIR (7B), and 3D PD TSE nDixon (7C) of the foot. The 3D PD SPAIR image **(7B)** demonstrates an artifactual edema-like signal (dotted white circle) involving the distal phalanx and adjacent soft tissues, whereas no corresponding artifact is observed on either the conventional MRI **(7A)** or the 3D PD TSE nDixon image **(7C)**.

6. Beyond the knee: Extending the concept to small joints

Although the knee is an ideal proof of concept, the potential of 3D PD TSE nDixon imaging extends well beyond this application. Small joints of the wrist, hand, fingers, ankle, and foot remain challenging because of their complex anatomy and the susceptibility of conventional SPAIR-based fat suppression to peripheral magnetic field inhomogeneities (Fig. 6). In these anatomical regions, isotropic 3D imaging allows multiplanar reformations precisely aligned with small ligaments, tendon insertions, pulleys, cartilage surfaces, and osteochondral structures, while Dixon reconstruction provides more robust fat suppression throughout the field of view (Fig. 7). Our initial experience suggests that these applications may benefit even more from the combination of isotropic imaging and Dixon reconstruction than the knee itself, and investigations are currently evaluating these indications.

7. Looking ahead

For many years, musculoskeletal MRI has sought to reduce the number of acquisitions without compromising diagnostic performance. The combination of isotropic 3D TSE imaging, Dixon fat–water separation, and deep-learning reconstruction brings this objective closer to routine clinical practice. Rather than considering 3D imaging as an additional sequence, it may now be viewed as the foundation of a comprehensive examination.

Our clinical experience demonstrates that a single 3D PD TSE nDixon acquisition provides comprehensive evaluation of menisci, ligaments, cartilage, fractures, and bone marrow abnormalities while reducing acquisition time by approximately 50%. The simultaneous availability of water-only and fat-only reconstructions further simplifies the examination by reducing dependence on dedicated T1-weighted imaging.

Rather than representing another incremental technical improvement, single-acquisition isotropic Dixon imaging may mark a genuine shift in musculoskeletal MRI — from protocols built around multiple individual sequences to comprehensive volumetric imaging capable of delivering the entire examination from a single acquisition.

Key benefits of 3D PD TSE nDixon

- One acquisition, four image contrasts
- Potential replacement of dedicated T1 imaging
- ~ 50% shorter examination time
- Isotropic multiplanar reformations
- Robust Dixon fat suppression
- Deep-learning reconstruction
- Motion-resistant workflow
- Potential extension to hand, wrist, ankle, and foot imaging

References

1 Bajaj S, Chhabra A, Taneja AK. 3D isotropic MRI of ankle: review of literature with comparison to 2D MRI. Skeletal Radiol [Internet]. 2024;53(5):825–46. Available from: http://dx.doi.org/10.1007/s00256-023-04513-2

2 Bacher S, Hajdu SD, Maeder Y, Dunet V, Hilbert T, Omoumi P. Differentiation between benign and malignant vertebral compression fractures using qualitative and quantitative analysis of a single fast spin echo T2-weighted Dixon sequence. Eur Radiol [Internet]. 2021;31(12):9418–27. Available from: http://dx.doi.org/10.1007/s00330-021-07947-1

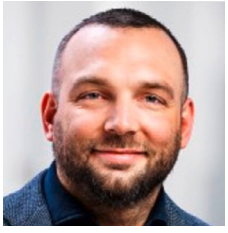
3 Gillet R, Boubaker F, Clara M, Ambarki K, Stemmer A, Drouot G, et al. Optimizing knee MRI: 3D proton density turbo spin echo nDixon sequence vs. 2D high-resolution turbo spin echo in half the acquisition time. Eur J Radiol [Internet]. 2026;195:112552. Available from: http://dx.doi.org/10.1016/j.ejrad.2025.112552

4 Omoumi P. The Dixon method in musculoskeletal MRI: from fat-sensitive to fat-specific imaging. Skeletal Radiol [Internet]. 2022;51(7):1365–9. Available from: http://dx.doi.org/10.1007/s00256-021-03950-1

5 Özgen A. The Value of the T2-Weighted Multipoint Dixon Sequence in MRI of Sacroiliac Joints for the Diagnosis of Active and Chronic Sacroiliitis. Am J Roentgenol [Internet]. 2017;208(3):603–8. Available from: http://dx.doi.org/10.2214/AJR.16.16774

6 Noorveriandi H, Cootes TF, Parkes MJ, Felson DT, O'Neill TW, Hodgson R. Quantification of fat fraction in subchondral bone marrow in knee osteoarthritis using Dixon MRI and image registration. Osteoarthr Imaging [Internet]. 2022;2(2):100067. Available from: http://dx.doi.org/10.1016/j.ostima.2022.100067

7 Maeder Y, Dunet V, Richard R, Becce F, Omoumi P. Bone Marrow Metastases: T2-weighted Dixon Spin-Echo Fat Images Can Replace T1-weighted Spin-Echo Images. Radiology [Internet]. 2018;286(3):948–59. Available from: http://dx.doi.org/10.1148/radiol.2017170325



Contact

Romain Gillet, M.D., Ph.D.
Service d'Imagerie Guilloz
Hôpital Central — CHRU Nancy
29 Avenue du Maréchal de Lattre de Tassigny
CO 60034
54035 Nancy Cedex
France