Radial UTE MRI in Musculoskeletal Diseases: Current Clinical Applications and Future Perspectives

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Introduction

Magnetic resonance imaging (MRI) is the modality of choice for evaluating most soft-tissue structures in the musculoskeletal system because of its excellent soft-tissue contrast and lack of ionizing radiation. However, conventional MRI sequences typically use echo times longer than one millisecond and therefore fail to capture signal from tissues with ultrashort transverse relaxation times, such as cortical bone, calcified cartilage, fibrocartilage, the deep or enthesial portions of tendons and ligaments, and cartilaginous endplate at the discovertebral junction [1, 2]. Because these short-T2 tissues are frequently involved in musculoskeletal disease, conventional MRI leaves a diagnostic gap that has traditionally been addressed by radiography or computed tomography (CT).

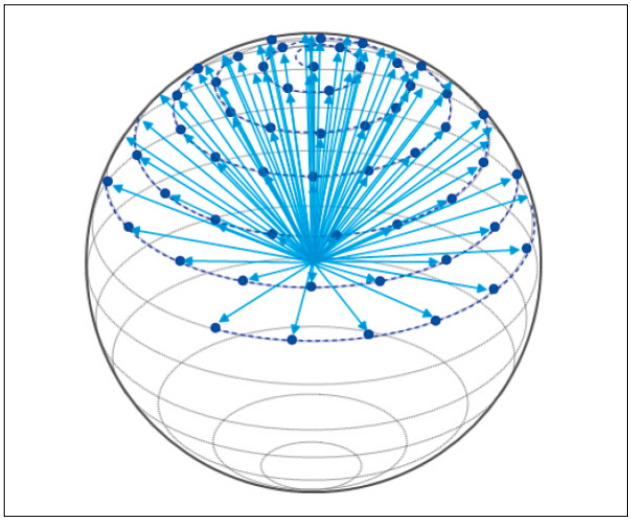
Three-dimensional (3D) radial ultrashort echo time (UTE)* MRI helps bridge this gap by sampling the free induction decay within tens of microseconds after non-selective excitation, using a center-out radial *k*-space trajectory [3]. This technique enables visualization of tissues that are normally signal-void on conventional MRI, and can provide CT-like contrast for cortical bone and mineralized tissue while preserving the soft-tissue advantages of MRI. As a result, radial UTE MRI has emerged as a promising adjunct to standard musculoskeletal MRI protocols, particularly when simultaneous assessment of bone, mineralized tissue, marrow, and soft-tissue structures is clinically desirable.

Technical principles of radial UTE MRI

Three-dimensional ultrashort echo time (3D UTE) imaging was performed using a center-out radial research application sequence with TE 40 µs [3]. A short nonselective radiofrequency (RF) block pulse (40 µs) was followed by immediate data sampling after transmit/receive switching. To minimize TE, data acquisition was initiated during the ramp-up of the readout gradient. *k*-space was sampled from the center to the periphery using an isotropic 3D radial "kooshball" trajectory (Fig. 1). Image reconstruction was performed via a non-uniform fast Fourier transform using Cartesian gridding with a Kaiser-Bessel window function. To reduce trajectory deviations, the *k*-space locations of the samples were estimated using a gradient impulse response function [4]. The imaging parameters are summarized in Table 1.

Clinical applications

The clinical value of 3D radial UTE MRI lies in its ability to depict cortical bone and mineralized tissue with CT-like contrast while retaining the soft-tissue information available from conventional MRI. In current musculoskeletal imaging practice, UTE is best understood as an additional sequence within a standard MRI protocol, rather than a stand-alone examination. The following sections summarize representative clinical applications in which UTE MRI may provide incremental diagnostic value.



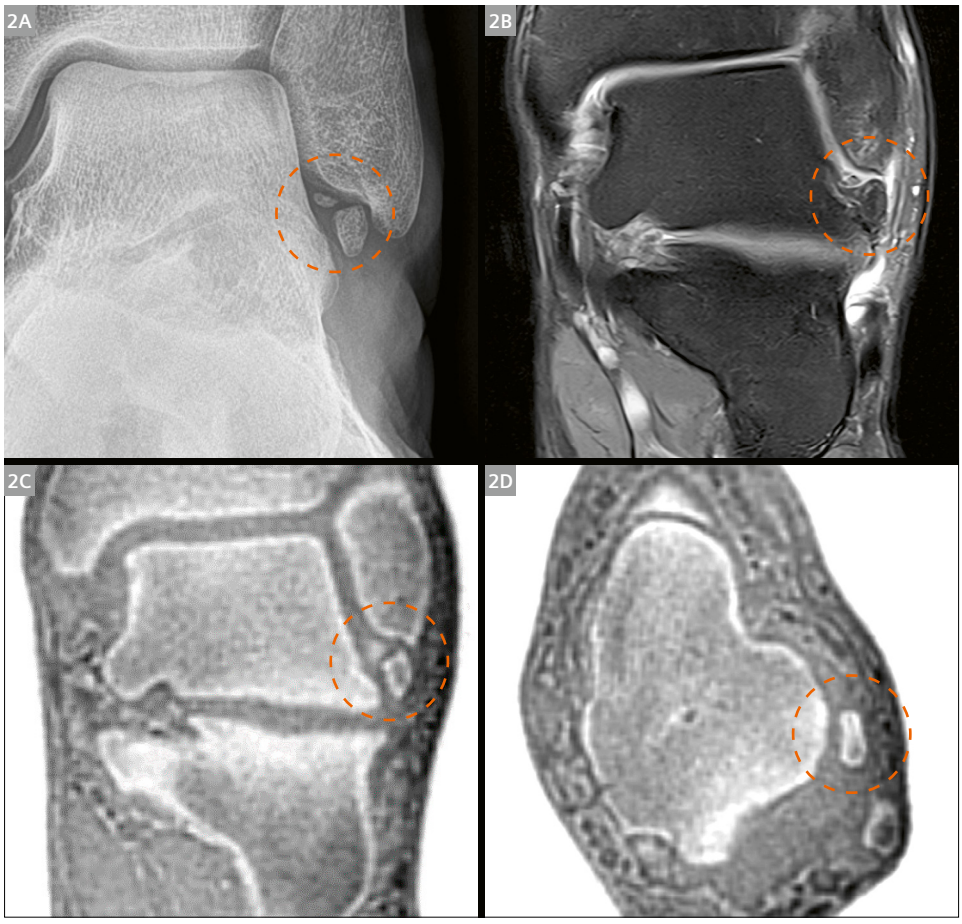
1 Schematic visualization of the radial sampling scheme.

*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.

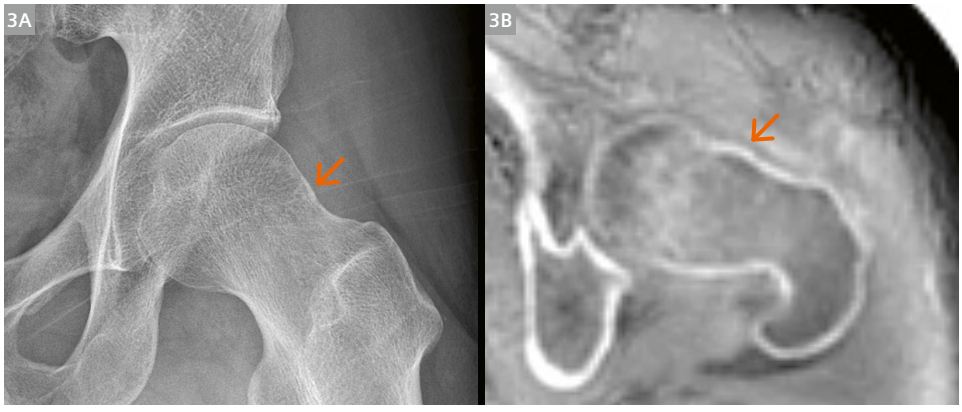
Bone morphology and cortical contour assessment

Accurate depiction of cortical contour and osseous morphology is fundamental in many musculoskeletal diagnoses [5]. On conventional MRI, cortical bone is usually seen as signal-void structure, which can make subtle cortical irregularity, osseous remodeling, or complex bony anatomy difficult to assess. Radial UTE MRI can improve visualization of cortical margins and bone morphology by providing CT-like contrast within an MRI examination [6, 7].

This capability is particularly useful in joints and anatomic regions where both osseous morphology and soft-tissue status are clinically relevant. For example, in the spine and appendicular skeleton, UTE MRI can depict cortical contour abnormalities while conventional MRI sequences demonstrate marrow edema, disc disease, ligamentous injury, synovitis, or soft-tissue pathology (Fig. 2). Thus, UTE MRI may complement routine MRI by integrating osseous and soft-tissue information in a single radiation-free examination (Fig. 3) [7, 8].



2 Symptomatic bipartite os subfibulare in a 22-year-old male with chronic ankle instability. Anteroposterior ankle radiograph **(2A)**, coronal fat-suppressed T2-weighted MR image **(2B)**, and coronal and axial UTE MR images **(2C, 2D)** demonstrate a bipartite os subfibulare. The ossicles (dotted circles) are more clearly delineated with CT-like cortical contrast on UTE than on the corresponding conventional MR image. The patient subsequently underwent surgical treatment.



3 Femoroacetabular impingement (cam type) in a 51-year-old male. Dunn-view radiograph **(3A)** and axial UTE MR image **(3B)** of the left hip demonstrate an osseous prominence (arrows) at the femoral head–neck junction, which is clearly delineated with CT-like cortical contrast on UTE.

Fractures

Fracture evaluation is another important application of radial UTE MRI. Fracture lines, cortical disruption, and displaced osseous fragments are often defined by cortical bone, which is poorly visualized on conventional MRI but can be depicted more directly with UTE-based imaging [7, 8]. UTE MRI may therefore improve confidence in identifying cortical breaks or small osseous fragments when conventional MRI findings are equivocal.

This approach may be especially advantageous when radiation avoidance is desirable, such as in children, young adults, pregnant patients when appropriate, or patients requiring repeated follow-up examinations (Fig. 4) [6, 9]. In addition, UTE MRI may be useful when both fracture morphology and associated marrow or soft-tissue injury need to be assessed. However, because CT still provides superior spatial resolution, UTE MRI should currently be regarded as complementary to CT rather than a universal substitute.

Focal bone lesions

In focal bone lesions, radial UTE MRI can add information about cortical integrity and matrix mineralization to the marrow and soft-tissue information provided by conventional MRI [9, 10]. Conventional MRI is highly sensitive for marrow replacement, edema, soft-tissue extension, endosteal scalloping, and aggressive features. However, it is less specific for mineralized matrix, cortical detail, and small calcified or ossified components.

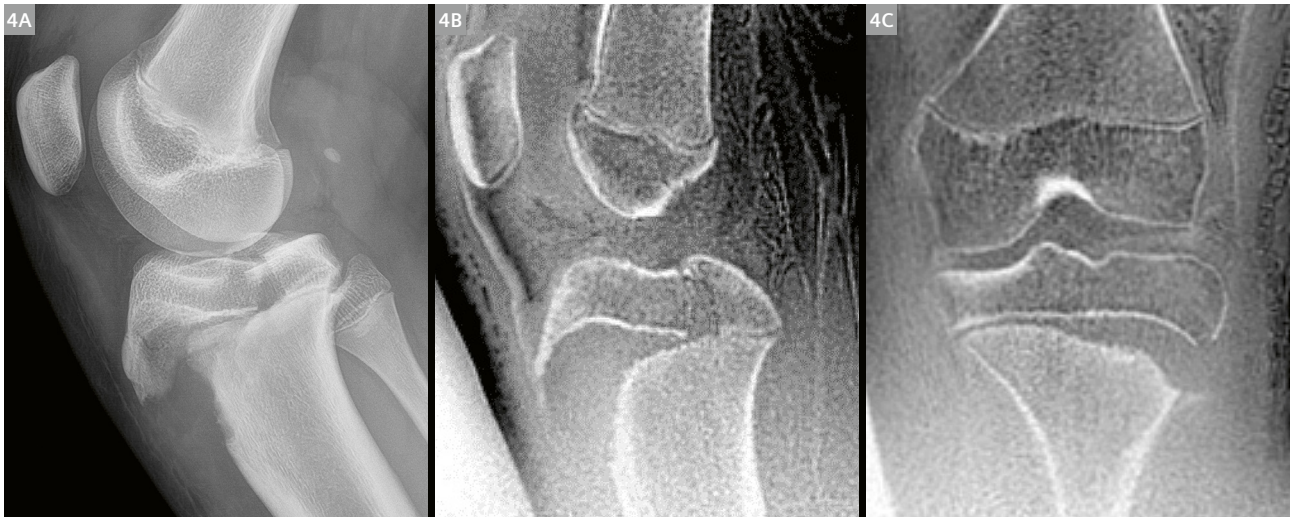
UTE MRI may help depict patterns of mineralization, including chondroid calcification, osteoid matrix, or nidus mineralization, while also demonstrating cortical involvement and associated pathologic fracture (Fig. 5). This information can be useful in lesion characterization, treatment planning, and follow-up. Nevertheless, CT remains superior when very fine mineralized matrix detail or subtle cortical destruction must be assessed with maximum spatial resolution.

Joint pathology

Radial UTE MRI may also contribute to the evaluation of degenerative, inflammatory, and infectious joint diseases by improving visualization of cortical and subchondral osseous abnormalities. These include osteophytes, subchondral sclerosis, erosions, osteolysis, and frank bony destruction [7, 8].

Parameters	3D radial UTE sequence
Radial view	40000
TR / TE (ms)	3.9 / 0.04
FOV (mm)	More than 200 mm
Flip angle (deg)	1.5°
Matrix	202 × 202
Slice thickness (mm)	0.7
Slices	288 slices per slab
Bandwidth (Hz/pixel)	1157
Acquisition time (min:sec)	5:13

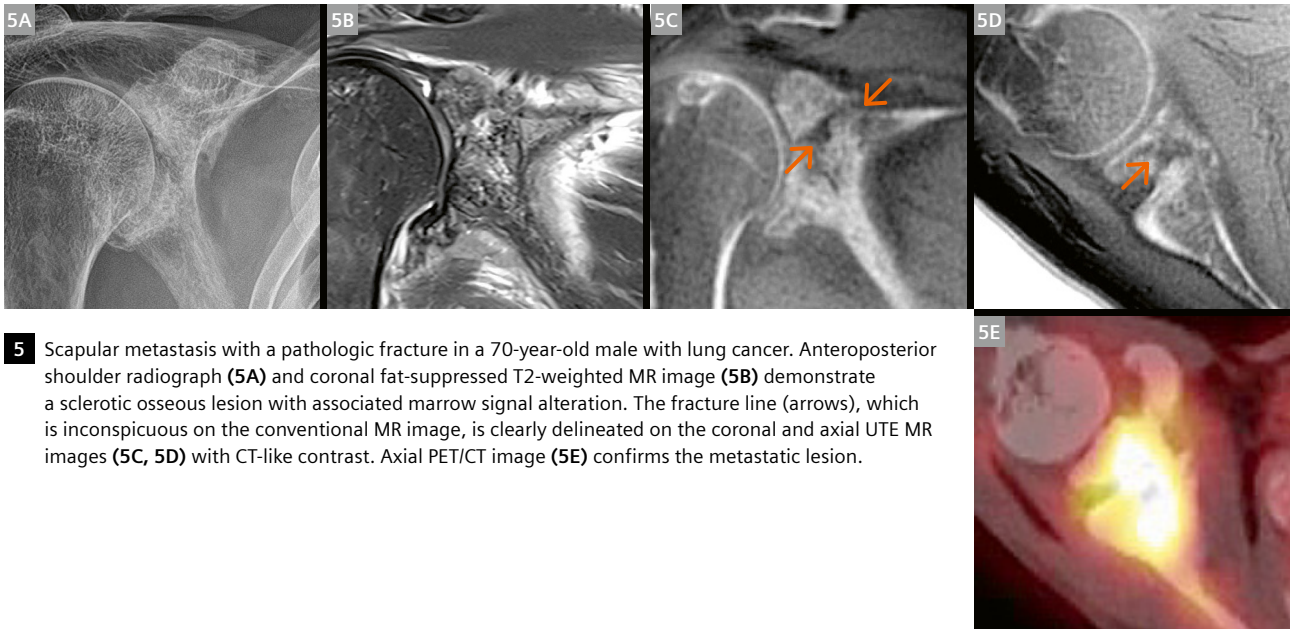
Table 1: 3T MAGNETOM Vida imaging parameters



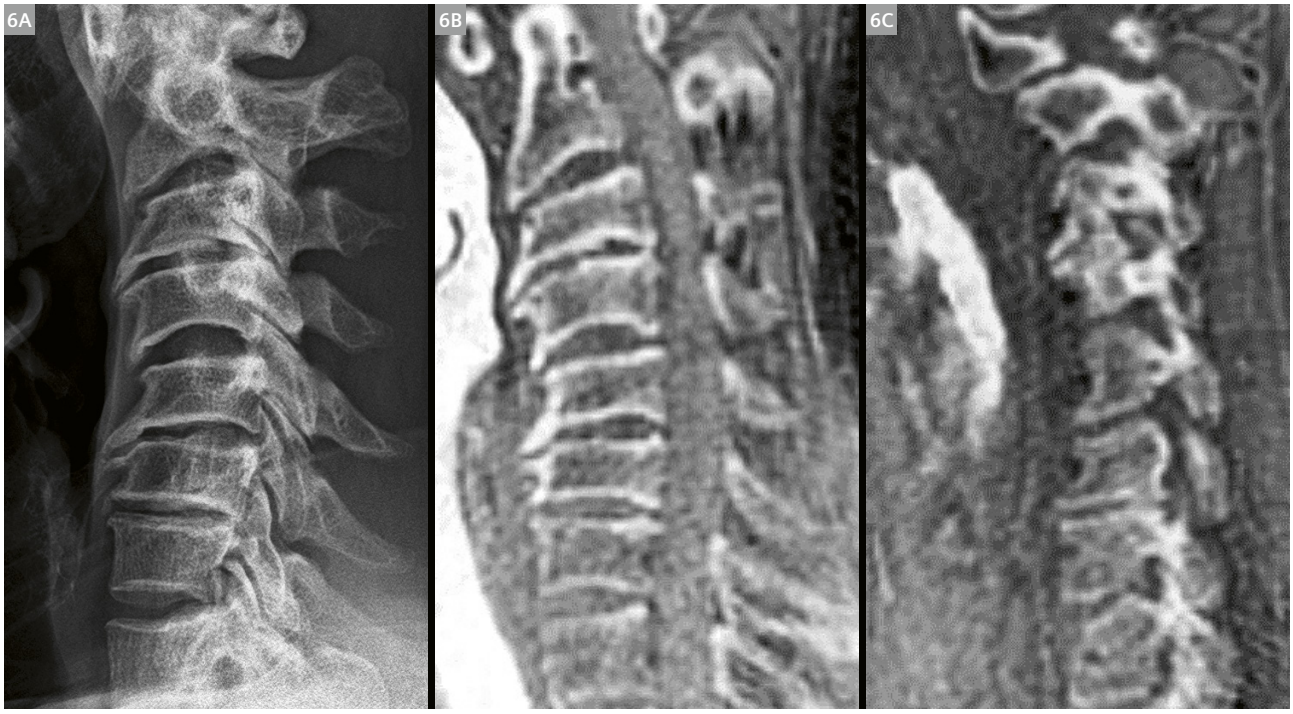
4 Tibial tuberosity avulsion fracture in a 13-year-old boy. Lateral knee radiograph **(4A)** and sagittal and coronal UTE MR images **(4B, 4C)** demonstrate a tibial tuberosity avulsion fracture extending through the proximal tibial physis and epiphysis with intra-articular extension. UTE MR images clearly delineate the fracture line and displaced fragment with CT-like cortical contrast.

In degenerative disease in the joints and spine, productive osseous changes such as osteophytes and subchondral remodeling are important markers of disease severity (Fig. 6). In this setting, UTE MRI may help provide a more comprehensive evaluation of both soft-tissue and osseous components of degenerative disease [7, 8].

In inflammatory arthritis, cortical erosions are clinically important because they reflect structural joint damage. UTE MRI may improve depiction of erosive change by better delineating cortical margins. Similarly, in infectious arthritis, early recognition and accurate mapping of cortical erosion or subchondral destruction are important



5 Scapular metastasis with a pathologic fracture in a 70-year-old male with lung cancer. Anteroposterior shoulder radiograph **(5A)** and coronal fat-suppressed T2-weighted MR image **(5B)** demonstrate a sclerotic osseous lesion with associated marrow signal alteration. The fracture line (arrows), which is inconspicuous on the conventional MR image, is clearly delineated on the coronal and axial UTE MR images **(5C, 5D)** with CT-like contrast. Axial PET/CT image **(5E)** confirms the metastatic lesion.



6 Cervical spondylosis in a 56-year-old male. Lateral cervical spine radiograph **(6A)** and sagittal UTE MR images **(6B, 6C)** demonstrate multilevel osteophytes, endplate sclerosis, and disc space narrowing. UTE clearly delineates these osseous degenerative changes with CT-like contrast.

for assessing disease severity and planning treatment. By combining UTE depiction of cortical destruction with conventional MRI findings such as joint effusion, synovitis, abscess, and marrow edema, MRI may provide a more complete radiation-free assessment of joint infection [6–8].

Soft-tissue calcification and ossification

Calcified and ossified soft-tissue deposits have short-T2 properties and may be difficult to characterize on conventional MRI, where they often appear as nonspecific low-signal foci. Radial UTE MRI can directly depict mineralized tissue and may therefore improve detection and characterization of soft-tissue calcification or ossification [8, 9].

This application is relevant in conditions involving calcific tendinopathy, heterotopic ossification, enthesopathic change, and other mineralized deposits within ligaments or periarticular soft tissues (Fig. 7). By clarifying whether a low-signal abnormality on conventional MRI represents mineralization, fibrosis, susceptibility artifact, or another process, UTE MRI may improve diagnostic specificity and help define disease extent [9].

Postoperative evaluation

Postoperative musculoskeletal imaging often requires assessment of both hardware and adjacent bone. Conventional MRI may be limited by susceptibility artifacts near metallic implants, while radiographs provide limited soft-tissue and marrow information. The very short echo time of UTE sequences can reduce susceptibility-related signal loss and distortion, and radial UTE-based approaches may improve visualization of bone and hardware-adjacent structures (Fig. 8) [11].

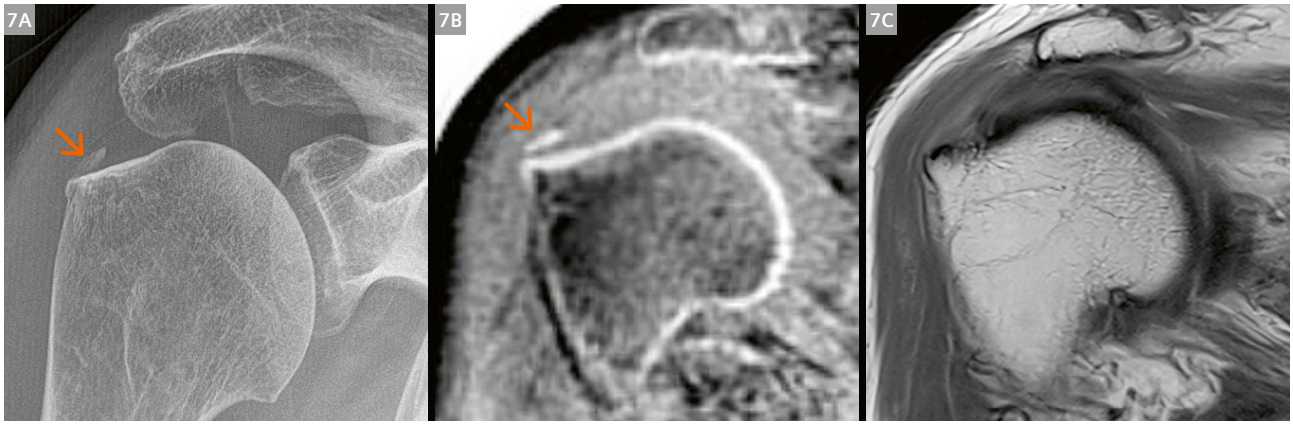
Advanced applications

Beyond morphologic imaging, UTE-based techniques enable quantitative assessment of short-T2 tissues. Quantitative UTE methods can estimate parameters such as T2*, T1, T1ρ, magnetization transfer ratio, macromolecular proton fraction, and porosity-related indices. These biomarkers are being investigated for evaluating cortical bone quality, tendon and ligament composition, cartilage degeneration, and other tissue-level changes that are difficult to assess with conventional MRI [2, 6, 8, 12–14].

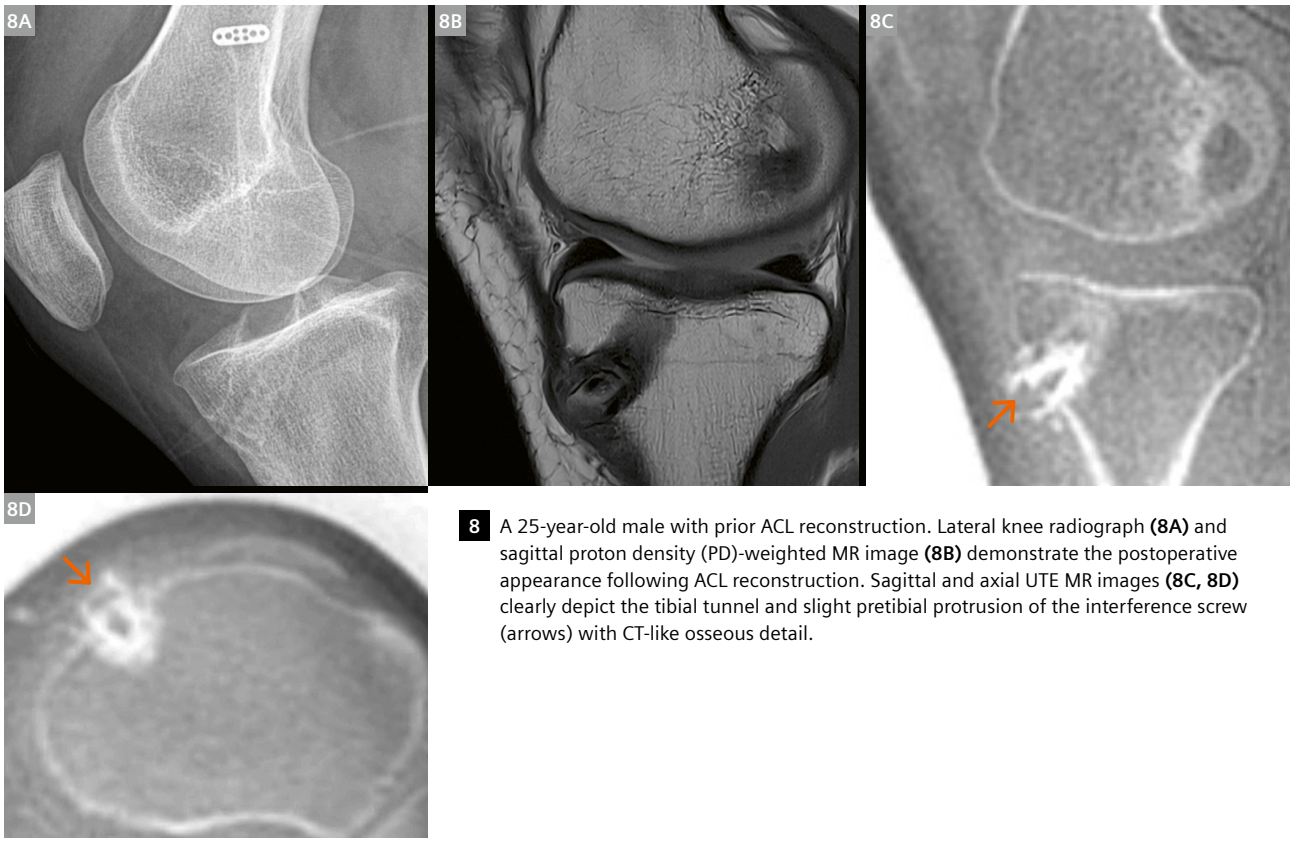
Emerging UTE-based approaches, including quantitative susceptibility mapping, conductivity mapping, and accelerated 3D radial acquisitions with deep learning reconstruction, may further expand the role of UTE MRI in musculoskeletal imaging. These methods remain largely investigational, but they suggest that UTE MRI may eventually contribute not only to structural visualization but also to quantitative tissue characterization.

Limitations and future directions

Despite its advantages, radial UTE MRI has several important limitations. First, although UTE can provide CT-like contrast, it does not yet match the spatial resolution, speed, or robustness of CT for fine cortical detail and subtle mineralization [7, 8, 13]. Second, radial UTE MRI may require longer acquisition times than conventional sequences, increasing susceptibility to patient motion. Nevertheless, the radial nature of the sequence is less susceptible to motion due to repeated sampling of the *k*-space center. Third, radial acquisitions can produce specific artifacts, including streak artifacts, blurring, chemical shift, and artifacts related to gradient imperfections. These artifacts may mimic or obscure pathology



7 Calcific tendinitis of the supraspinatus in a 75-year-old female. The calcific deposit (arrows) is clearly depicted on the 30° caudal tilt radiograph **(7A)** and the inverted grayscale UTE MR image **(7B)**, which provides CT-like contrast; it appears ambiguous on the corresponding proton density (PD)-weighted MR image **(7C)**.



8 A 25-year-old male with prior ACL reconstruction. Lateral knee radiograph **(8A)** and sagittal proton density (PD)-weighted MR image **(8B)** demonstrate the postoperative appearance following ACL reconstruction. Sagittal and axial UTE MR images **(8C, 8D)** clearly depict the tibial tunnel and slight pretibial protrusion of the interference screw (arrows) with CT-like osseous detail.

if not recognized. Technical optimization and careful interpretation are therefore essential [12, 15, 16]. Finally, incomplete standardization remains a barrier to broader clinical adoption. However, ongoing advances in accelerated acquisition and image reconstruction, including deep learning-based reconstruction, are improving image quality while reducing scan times. Together with further clinical validation and protocol harmonization, these developments are expected to enhance the clinical feasibility of radial UTE MRI and facilitate its broader integration into routine musculoskeletal imaging across institutions [17].

Conclusion

Radial UTE MRI is a rapidly evolving technique that expands the diagnostic capability of musculoskeletal MRI by enabling visualization of tissues that are poorly seen on conventional sequences. By recovering signal from short-T2 structures and providing CT-like contrast for cortical bone and mineralized tissue, UTE MRI can complement standard MRI in the evaluation of bone morphology, fractures, focal bone lesions, joint disease, soft-tissue calcification or ossification, and postoperative changes.

At present, radial UTE MRI is best regarded as a powerful adjunct to, rather than a replacement for, CT or conventional MRI. Its clinical role is partially limited by longer acquisition times, sequence-specific artifacts, magic-angle effect, and lower spatial resolution compared with CT. Nevertheless, continuing advances in acquisition and reconstruction are likely to expand the role of radial UTE MRI in comprehensive, radiation-free musculoskeletal imaging.

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