Ultra High Field (7 Tesla) MRI for Musculoskeletal Applications

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Since the end of the 1990s, high field MRI operating at 3 Tesla has become the benchmark for routine clinical applications, as well as for clinical MRI research. The clinical benefits of the double signal-to-noise ratio (SNR) compared to standard 1.5 Tesla MRI lie predominantly in the possibility of combining morphological and functional high-field MR methods, such as functional MR, metabolic imaging, and diffusion-weighted imaging.

In the early 2000s, the MRI field strength was again increased by another factor of approximately two and at least three major MR vendors currently provide commercial 7 Tesla systems for human clinical research under approved ethical permission. During the last several years, the number of 7 Tesla installations finalized or under preparation has increased to about 50.

While clinical MR research centers operating at 7 Tesla mostly focus on neuro-logical applications, only a few 7 Tesla sites perform whole-body clinical research. This is because of the limited availability of suitable coils for 7 Tesla, which have to be transmit and receive coils, and because of the higher B1 homogeneity related to the ultra high field. Other limitations relate to the safety issues, particularly the increased specific absorption rate (SAR).

Due to the relatively small volumes of joints in comparison to brain or abdomen for example, a higher B0 and B1 homogeneity is easier to study in musculoskeletal applications. While in morphological imaging the spatial resolution can be increased within the same scan time compared to 3 Tesla, compositional or biochemical MR of cartilage and other joint structures benefit from the higher SNR at 7 Tesla. Moreover, nuclei other than protons can be used at 7 Tesla. Sodium values which correlate directly with the glycosaminoglycan content of cartilage, as well as other MSK structures such as the tendons and the intervertebral disc, have been used in clinical applications for the first time [1]. The same is true for Chemical Exchange Saturation Transfer (CEST), which is a very modern glycosaminoglycan (GAG)-specific technique [2]. This image gallery gives an overview of musculoskeletal applications at 7 Tesla.

CAUTION: The 7T system is an investigational device. Limited by U.S. federal law to investigational use. The products mentioned herein are still under development and not commercially available yet. Its future availability cannot be ensured. This research system is not cleared, approved or licensed in any jurisdiction for patient examinations. This research system is not labelled according to applicable medical device law and therefore may only be used for volunteer or patient examinations in the context of clinical studies according to applicable law.
Case 1

Coronal fat-saturated (fs) 2D proton density-weighted turbo spin echo (PD TSE) sequence for 3T (1A), 7T quick (same resolution compared to 3T, but shorter scan time at 7T) (1B) and 7T high-resolution (same scan time compared to 3T, but higher resolution at 7T) (1C) measurements. The medial femoral condyle with the medial meniscus is enlarged for better visualisation of the image quality.

The sagittal fat-saturated isotropic 3D PD-TSE sequence, called PD SPACE (sampling perfection with application-optimised contrasts using different flip angle evolutions), is shown for the 3T and two 7T protocols (see above).
Case 2

Sagittal 2D SE of the healthy ankle of a 25-year-old volunteer at 3T (2A) and 7T (2B).
Coronal 2D TSE of the healthy ankle of a 25-year-old volunteer at 3T (2C) and at 7T (2D).
Case 3

PD fs grayscale image of the wrist (3A), T1-weighted wrist image (3B) and image of fingers, showing cartilage of small joints (3C).

Case 4

Sagittal knee image of a 58-year-old male patient, 9.4 years after Autologous Osteochondral Transplantation (AOT) at the medial femoral condyle. (4A) Morphologic PD-TSE image. (4B) Graphical overlay with T$_2$-map. Colorbar represents relaxation times in [ms]; higher values = more water, disturbed collagen architecture. (4C) Graphical overlay with gagCEST image. Colorbar represents gagCEST asymmetries in [%]; lower values, less PG content. (4D) Graphical overlay with Sodium image. Colorbar represents the Sodium SNR values; lower values, less PG content. Note, that with all modalities degenerative changes are seen in the area of AOT.
Case 5

Axial knee images from a 25-year-old male patient after matrix-associated chondrocyte transplantation (MACT) in the retropatellar cartilage (L). Cartilage adjacent to the lesion (AT) appears morphologically intact on PD-TSE image (5A) and appears normal on the color-coded overlay of T2-map (5B). However on color-coded overlay of gagCEST (5C) and color-coded overlay of Sodium image (5D) lower values in adjacent cartilage is seen, corresponding to a lower GAG content.
Case 6

T₂-mapping of the ankle joint cartilage layer at 7T (6A). In (6B) the regions-of-interest for the zonal analysis are superimposed onto the cartilage layer of the talus.
Case 7

The comparison of the sodium signal in a healthy volunteer (7B) and in a patient with Achilles tendinopathy (7D). Corresponding morphological images are on the left-hand side, 7A and 7C respectively. Higher sodium image intensity (white arrows) in case of the patient with chronic Achilles tendinopathy corresponds to the higher GAG content found in such patients (7D) in comparison to healthy tendons (7B).
Case 8

7T Sodium imaging (8A) and 3T color-coded image of T2-mapping (8B) in a volunteer without disc degeneration.

References