

Magnetic Resonance Imaging of the Musculoskeletal System at 7T

Morphological Imaging and Beyond

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Abstract: In 2017, a whole-body 7T magnetic resonance imaging (MRI) device was given regulatory approval for clinical use in both the EU and United States for neuro and musculoskeletal applications. As 7 Tesla allows for higher signal-to-noise, which results in higher resolution images than those obtained on lower-field-strength scanners, it has attracted considerable attention from the musculoskeletal field, as evidenced by the increasing number of publications in the last decade. Besides morphological imaging, the quantitative MR methods, such as T_2 , T_2^* , $T_{1\rho}$ mapping, sodium imaging, chemical-exchange saturation transfer, and spectroscopy, substantially benefit from ultrahigh field scanning. In this review, we provide technical considerations for the individual techniques and an overview of (mostly) clinical applications for the assessment of cartilage, tendons, meniscus, and muscle. The first part of the review is dedicated to morphological applications at 7T, and the second part describes the most recent developments in quantitative MRI at 7T.

Key Words: 7 Tesla, cartilage, meniscus, muscle, musculoskeletal, quantitative, tendons, ultrahigh-field

(*Top Magn Reson Imaging* 2019;28:125–135)

Although 7T magnetic resonance (MR) scanners have been in operation in many large hospitals and research centers for more than a decade, only recently have the regulatory authorities given approval for clinical use. The first European regulatory approval, in July 2017, for a clinical 7 Tesla MRI was followed by the U.S. Food and Drug Administration (FDA), which cleared the first clinical 7 Tesla MRI scanner in North America at the Mayo Clinic in October 2017.^{1,2} Musculoskeletal clinical applications are widespread on standard field strengths, such as 1.5 and 3T MR scanners. Ultrahigh field MR scanners provide, however, significant improvements in signal gain, a shortened scan time, or increasing spatial resolution. In theory, as MR signal

amplitude is linearly proportional to the net magnetic polarization of the (mostly commonly imaged) hydrogen nuclei, signal should increase by a factor of 2.3 between 3 and 7 Tesla. As the noise also increases slightly between the 2 field strengths (physiological noise increases with the square of the main field strength), the signal-to-noise (SNR) ratio increases approximately by a factor of 2.³ This fact can be exploited either by shortening the scan time for particular protocols or by increasing the spatial resolution while maintaining the other parameters, such as field-of-view; the same. This gain is, however, not straightforward, due to inherent obstacles of ultrahigh field MR scanners. Radio-frequency (RF) deposition, measured by specific absorption rate (SAR), is much higher, which results in greater heating of the tissue. B_1 inhomogeneity is also a considerable problem of ultrahigh field MR scanners, that is, the shortened wavelength (~ 1.5 cm) causes difficulties in penetrating the body and the scanner does not work in the near field regime anymore.³ In the early days of 7 Tesla, B_1 inhomogeneity and subsequent challenges in 7T coil construction resulted in the lack of dedicated coils for many tissues and organs of interest. However, recent developments, driven by the demand from the MR community, show a positive outlook. In addition to neuroimaging, spectroscopy, and X -nuclei applications, the musculoskeletal (MSK) system is one of the main targets of ultrahigh-field MR. One of the most frequently imaged MSK tissue is articular cartilage. Increased age of the population and the incidence of obesity have led to one of the most prevalent MSK conditions—osteoarthritis (OA). OA is a complex joint disease that, in addition to cartilage, also affects the menisci, the synovium, and other tissues of the joint. Conventional modalities, such as radiographs and morphological MRI, are reliable for the detection of the symptoms of late OA stages (joint space narrowing or cartilage tissue loss). There is, however, a strong demand for techniques that provide information about the early structural changes of cartilage, thereby offering an opportunity for early interventions. Quantitative MR techniques have a great potential to establish the imaging markers for glycosaminoglycan (GAG) loss and collagen fiber remodeling. Ultrahigh field scanners provide the basis for the improvement of GAG-specific techniques [chemical exchange saturation transfer (gagCEST) and sodium MRI] and collagen-specific techniques (T_2 and T_2^* mapping, magnetization transfer). Also, focal cartilage lesions after injuries and repair tissue after cartilage repair surgeries are of interest for imaging modalities to avoid the multiple biopsies required for follow-up of patients after treatment. Ultrahigh field MR is very powerful in imaging rapidly relaxing tissues, including tendons, menisci, ligaments, and bones. Higher SNR at 7T enables an accurate estimation of mono- and multicompartment relaxation rates in tendons, calcified cartilage, and bones. Degenerative disk disease (DDD) has received much literature attention in the last several years, as the incidence of intervertebral disk (IVD) disease has steadily increased. As for tendons, in addition to the acute complete tear, other abnormalities, such as tendinopathy, intratendinous necrosis, and partial tears, are relatively common. Skeletal muscle is another important target tissue for MSK imaging and spectroscopy, as many metabolic and degenerative

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Received for publication December 6, 2018; accepted March 6, 2019.
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Funding for this study was provided by Austrian Science Fund (FWF) K1254-B30, The Sir Henry Dale Fellowship from the Wellcome Trust and the Royal Society (Grant Number 098436/Z/12/B), Slovak Grant Agency APVV-15-0029. The authors report no conflicts of interest.

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 - The Rise of Digital Reading Magnetic Resonance Of The Musculoskeletal System
 - Advantages of eBooks Over Traditional Books
2. Identifying Magnetic Resonance Of The Musculoskeletal System
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Magnetic Resonance Of The Musculoskeletal System
 - User-Friendly Interface
4. Exploring eBook Recommendations from Magnetic Resonance Of The Musculoskeletal System
 - Personalized Recommendations
 - Magnetic Resonance Of The Musculoskeletal System User Reviews and Ratings
 - Magnetic Resonance Of The Musculoskeletal System and Bestseller Lists
5. Accessing Magnetic Resonance Of The Musculoskeletal System Free and Paid eBooks

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 - Magnetic Resonance Of The Musculoskeletal System eBook Subscription Services
 - Magnetic Resonance Of The Musculoskeletal System Budget-Friendly Options
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 - Magnetic Resonance Of The Musculoskeletal System Compatibility with Devices
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 - Highlighting and Note-Taking Magnetic Resonance Of The Musculoskeletal System
 - Interactive Elements Magnetic Resonance Of The Musculoskeletal System
 8. Staying Engaged with Magnetic Resonance Of The Musculoskeletal System
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Magnetic Resonance Of The Musculoskeletal System
 9. Balancing eBooks and Physical Books Magnetic Resonance Of The Musculoskeletal System
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Magnetic Resonance Of The Musculoskeletal System
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Magnetic Resonance Of The Musculoskeletal System
 - Setting Reading Goals Magnetic Resonance Of The Musculoskeletal System
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Magnetic Resonance Of The Musculoskeletal System
 - Fact-Checking eBook Content of Magnetic Resonance Of The Musculoskeletal System
 - Distinguishing Credible Sources
 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

- Exploring Educational eBooks
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- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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