Morphological and Quantitative 7 T MRI of Hip Cartilage Transplants in Comparison to 3 T—Initial Experiences

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Objectives: The aims of this study were to evaluate morphological and quantitative 7 T magnetic resonance imaging (MRI) hip sequences in patients after acellular cartilage transplantation and to compare image quality with 3 T MRI.

Materials and Methods: Following approval from the local institutional ethics committee and signing informed consent, 9 patients with history of autologous acellular cartilage transplantation were imaged at 3 T and 7 T MRI. Sequences (3-dimensional dual echo steady state, 3-dimensional T1 volume interpolated breath-hold examination, sagittal proton density [PD] turbo spin echo and coronal fat-saturated PD spin echo, sagittal T1 mapping in dual flip angle technique, and multiecho spin echo/gradient echo sequences for T2 and T2* mapping) were applied according to the intravascular application of GD-DTPA according to a protocol for delayed gadolinium-enhanced MRI of cartilage and manual B1 shimming at 7 T. Images were compared individually regarding image quality and assessability of cartilage structures using 5-point scales (1 = 3 T clearly superior, 5 = 7 T clearly superior) in consensus with 2 radiologists. Contrast ratios were calculated between articular cartilage, joint fluid, and subchondral bone. An adapted MOCART (MR observation of cartilage repair tissue) score was assessed independently at 3 T and 7 T. Relaxation times were measured in the transplanted acetabular region and in 2 reference regions by 2 readers independently to calculate interreader reliability. Statistical significances of field strength comparisons were calculated using Student t test and r test for dependent measurements.

Results: A 7 T MRI was superior to 3 T MRI in the majority of the sequences regarding subjective ratings. Furthermore, 7 T yielded comparable or better contrast ratios compared with 3 T. The criteria of the MOCART score matched totally at 3 T and 7 T, apart from the signal intensity of the repair tissue in PDw, which was rated higher at 7 T in 5 patients. Interreader reliability of all relaxation times was excellent. T1 and T2* relaxation times were significantly shorter at 7 T compared with 3 T. T2 relaxation times were longer at 7 T compared with 3 T without statistical significance. No significant difference could be seen when comparing the relaxation ratios (relaxation times after standardization to reference regions) of the cartilage transplants between the 2 field strengths.

Conclusions: This study shows the feasibility of morphological and quantitative 7 T hip MRI in patients after acellular cartilage transplantation and its predominant superiority regarding image quality, assessment of cartilage transplants, and contrast over 3 T MRI. To compare relaxation times between the field strengths, the calculation of intradividual ratios is recommended.

Key Words: ultrahigh-field MRI, 7 T, hip cartilage, dGEMRIC, T1 mapping, T2 mapping, T2* mapping, autologous cartilage transplantation, femoroacetabular impingement

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Joint preserving therapies have become increasingly common during the last years, especially for young patients with posttraumatic cartilage lesions, defects resulting from femoroacetabular impingement, or childhood diseases. While treatment options such as microfracture or autologous cartilage transplantation (ACT) have become standard procedures in the knee, the application of these minimally invasive techniques in the hip is still subject to few specialized orthopedic surgeons. Moreover, the noninvasive follow-up of cartilage repair procedures in the hip using magnetic resonance imaging (MRI) is more challenging compared with other joints because of the thin cartilage layer, the spherical shape of the joint, and the close contact between articular and femoral cartilage surface, and the deep anatomical region, making the use of dedicated anatomically customized radiofrequency (RF) surface coils impossible. One solution to improve the spatial resolution of the MRI scans and therefore the assessability of cartilage structures in the hip is the use of higher magnetic field strengths: the application of 7 T MRI has already shown superiority over lower field strengths in imaging several parts of the musculoskeletal system, especially in terms of spatial resolution, tissue contrast, or reduced examination time.

Besides morphological MR sequences, which provide information about the macroscopic structure of a tissue, quantitative sequences can deliver insights into the biochemical composition of a tissue. In cartilage imaging, the quantification of T1, T2, and T2* relaxation times among others is used to measure the amount of glycosaminoglycan and image the orientation of collagen, both being a marker of cartilage vitality. Compositional changes of enchondral tissue and therefore changes in relaxation times occur even before macroscopic changes are seen. Therefore, quantitative techniques can be used as an early marker of cartilage degeneration and for the assessment of cartilage transplants. These techniques, particularly when applied in the hip, require a high spatial resolution to distinguish between the articular and femoral cartilage layer and to be able to measure changes in relaxation times of small dedicated zones.

The ability to perform high-resolution morphological and quantitative MRI of hip cartilage at 7 T has been shown previously in a volunteer study. However, according to the best of our knowledge, the application of these techniques in patients and the comparison to lower field strengths have not been investigated yet.

Therefore, the aims of this study were to evaluate morphological and quantitative 7 T hip MRI in patients after acellular cartilage transplantation and to compare image quality with 3 T MRI.

MATERIALS AND METHODS

Patients

Approval from the local institutional ethics committee was gained before the study. Participants were recruited after screening a
database of 1 particular orthopedic surgeon that included all patients who underwent ACT of acetabular cartilage between August 2012 and November 2013. Autologous cartilage transplantation was conducted via an arthroscopic approach using 3-dimensional spheroids without scaffold membranes. Patients with subsequent hip surgeries, implants incompatible to 7 T MRI, renal insufficiency, or claustrophobia were excluded. Finally, 9 patients (1 female, 8 male; mean age, 40.5 ± 11.7 years [range, 23–55 years]; mean body mass index, 24.3 ± 2.1 kg/m² [range, 20.8–27.4 kg/m²]) gave informed consent to participate. The treated hip (7 right hips, 2 left hips; mean time after ACT, 19.3 ± 6.2 months [range, 10–29 months]) was imaged at 7 T first and at 3 T secondly after a mean delay of 20.6 ± 8.7 days (range, 13–36 days) between October 2014 and March 2015.

MR System and RF Transmitter Adjustments

For 7 T imaging, a whole-body research MRI system (Magnetom 7 T; Siemens Healthcare GmbH, Germany) with an in-house developed 8-channel RF transmit/receive body coil, consisting of 2 arrays with 4 elements each placed ventrally and dorsally on the pelvis in a central position, was used. To correct for B1 inhomogeneities, manual B1 shimming was conducted on the 7 T system; for the 2 left hips, the second-order circularly polarized (CP2+) transmit mode yielded homogeneous excitation over the joint at 7 T, whereas for the 7 right hips, a subject-individual RF shimming had to be calculated from relative B1 maps.15 The 3 T imaging took place on a clinical MRI system (Magnetom Skyra; Siemens Healthcare GmbH, Germany) using 16 active receive elements out of a 32-channel RF spine array located in the table in combination with a flexible 18-channel RF body matrix coil placed on the pelvis (both vendor provided) as used in clinical routine. At 7 T, presaturated turbo FLASH flip angle maps were used to automatically correct the T1 relaxation times in the postprocessing algorithm of the vendor-provided software (Syngo MapIt; Siemens Healthcare GmbH, Germany). At 7 T, flip angle maps obtained with the dual refocusing echo acquisition mode (DREAM)16,17 were used to adjust the RF transmit power manually dependent on the achieved flip angle, as described before.13

Imaging Protocol

Before being positioned in the scanner, every patient received 0.2 mmol/kg body weight Gd-DTPA2− (Magnevist; Bayer Healthcare, Leverkusen, Germany) intravenously and had to perform half an hour of walking and half an hour of rest according to a protocol for delayed gadolinium-enhanced MRI of cartilage (dGEMRIC).18 The time between contrast agent administration and T1 mapping, as well as the exact positioning of the patients with the use of comparable positioning aids and fixation of the feet in a neutral position, was kept as identical as possible between 3 T and 7 T.

Detailed information on sequence parameters is given in Table 1. For morphological imaging, 3-dimensional (3D) dual echo steady state (DESS), 3D T1 volume interpolated breath-hold examination (VIBE), and sagittal proton density (PD) turbo spin echo (TSE), and coronal fat-saturated (fs) PD TSE sequences were used. Fat suppression at 7 T was achieved by modifying the amplitudes of the slice-selective gradients.19 Sagittal T1 mapping was done using a 3D spoiled fast gradient echo (3D FLASH) sequence with 2 different excitation flip angles of 4 and 25 degrees at 7 T and 5 and 26 degrees at 3 T. For sagittal T2 and T2* mapping, multicontrast spin echo and gradient echo sequences with 5 echoes each were applied. Color-coded relaxation time maps were calculated automatically using vendor-provided software (Syngo MapIt).

The 7 T hip cartilage imaging protocol was adopted to be as equivalent as possible to the 3 T system (ie, in terms of resolution, echo time, repetition time, and scan time) to ensure a maximum of comparability. However, as the 7 T PDw TSE sequences were modified by the vendor to resolve limitations in the specific absorption rate at 7 T (Gaussian refocusing pulses with prolonged duration and peak flip angle at the center of k-space reduced to 160 from 180 degrees), in the sagittal plane, a standard PDw TSE sequence with comparable resolution and image contrast was used at 3 T. In the coronal plane, a 3D PDw fs TSE sequence with variable flip angle (called SPACE, sampling perfection with application optimized contrasts using different flip angle evolution) and an isotropic resolution of 0.8 mm was used at 3 T, which had been shown to be advantageous in previous studies on imaging cartilage repair tissue.20,21 However, as this technique needs a

### Table 1. Sequence Parameters at 7 T and 3 T

<table>
<thead>
<tr>
<th>Sequence type</th>
<th>B1* Mapping</th>
<th>T1 Mapping</th>
<th>T2 Mapping</th>
<th>T2* Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orientation</strong></td>
<td><strong>7 T</strong></td>
<td><strong>3 T</strong></td>
<td><strong>7 T</strong></td>
<td><strong>3 T</strong></td>
</tr>
<tr>
<td>TR, ms</td>
<td>Axial</td>
<td>Axial</td>
<td>Sagittal</td>
<td>Sagittal</td>
</tr>
<tr>
<td><strong>TE, ms</strong></td>
<td>6.3</td>
<td>5280</td>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td><strong>FOV, mm</strong></td>
<td>180</td>
<td>200</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td><strong>Slice thickness, mm</strong></td>
<td>2.5 × 2.5</td>
<td>3.1 × 3.1</td>
<td>0.4 × 0.4</td>
<td>0.5 × 0.5</td>
</tr>
<tr>
<td><strong>Slice resolution</strong></td>
<td>5</td>
<td>8</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>No. slices</strong></td>
<td>100%</td>
<td>100%</td>
<td>77%</td>
<td>77%</td>
</tr>
<tr>
<td><strong>Distance factor</strong></td>
<td>100%</td>
<td>50%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td><strong>Bandwidth, Hz/px</strong></td>
<td>620</td>
<td>490</td>
<td>280</td>
<td>230</td>
</tr>
<tr>
<td><strong>PAT</strong></td>
<td>None</td>
<td>None</td>
<td>2 (GRAPPA)</td>
<td>2 (GRAPPA)</td>
</tr>
<tr>
<td><strong>Acquisition time, min</strong></td>
<td>0:08</td>
<td>0:11</td>
<td>5:13</td>
<td>5:11</td>
</tr>
</tbody>
</table>

*Acquired 2 times for gap filling (reason: SAR limits at 7 T).
†Acquired with 2 averages.

DESS indicates 3-dimensional dual echo steady state; VIBE, volume interpolated breath-hold examination; PD, proton density; TSE, turbo spin echo; fs, fat-saturated; TR, repetition time; TE, echo time; FOV, field of view; PAT, parallel acquisition technique; GRAPPA, generalized autocalibration with partially parallel acquisition.
higher number of RF receive channels than available at 7 T, it could not be implemented in the 7 T protocol. Furthermore, the high in-plane resolution of 0.4 × 0.4 mm² in the 7 T T1 mapping sequence could not be adopted at 3 T because of too much noise; a resolution of 0.5 × 0.5 mm² was used instead.

### Image Evaluation

A subjective field strength comparison regarding overall image quality, the distinction of articular cartilage, and femoral cartilage as well as the delineation of the cartilage transplant or remaining defects was done in consensus with 2 radiologists (reader A, 5 years dedicated experience in cartilage imaging; reader B, 3 years dedicated experience in cartilage imaging), rating every sequence separately with side-by-side view of 3 T and 7 T on a 5-point scale (1 = 3 T clearly superior; 2 = 3 T slightly superior, 3 = 3 T and 7 T equal, 4 = 7 T slightly superior, 5 = 7 T clearly superior).

Quantitatively, the field strengths were compared using contrast ratios; for this purpose, a region of interest (ROI) was placed in a representative position of articular cartilage, joint fluid, and subchondral bone in every morphological sequence by reader A. Contrast ratios were subsequently calculated by CR = (signal A − signal B)/(signal A + signal B).

For the morphological evaluation of the cartilage transplant, an adapted score for MR observation of cartilage repair tissue (MOCART score, maximum 85 points²⁶) was assessed in consensus with reader A and B, using the PD- and T1-weighted images. The evaluation was done independently at 3 T and 7 T with a time in between the evaluations of 6 weeks.

Relaxation times were measured in the transplanted acetabular region, called ACT, as well as in 2 reference regions, namely, the corresponding femoral cartilage, called Ref1, and the dorsally adjacent healthy acetabular cartilage at the same slice position, within an angle of 10 to 30 degrees dorsal of the z-direction, called Ref2. For this purpose, the source images (image of the second flip angle for T1 calculation, image of the second echo for T2 and T2* calculation) were linked with the calculated color-coded relaxation time maps. The ROIs were placed in the source image by reader A and automatically transferred to the relaxation time map, where the values were registered. To ensure that the positions measured were as similar as possible at 3 T and 7 T, both examinations of each patient were displayed side-by-side for evaluation, and the slices which showed the cartilage and best position agreement between the 2 field strengths were chosen. These measurements were done a second time by reader B independently, who was aware of the previously analyzed slice positions but not of the exact placement nor the size or shape of the ROIs.

### Statistical Analysis

Statistical analysis was performed using SPSS Statistics 19 (IBM). Both quantitative and qualitative data was averaged over all patients. Values are given as mean ± standard deviation.

Contrast ratios were compared between the field strengths using Student *t* test. Interobserver reliability of the measured relaxation times was estimated by means of intraclass correlation (ICC, 2-way mixed, absolute agreement) and coefficient of variation (CV). After proving a normal distribution by a Shapiro-Wilk test, relaxation times were compared between the field strengths using the *t* test for dependent measurements, with *P* < 0.05 considered statistically significant. To standardize the relaxation times of the transplanted region intra-individually and to calculate a relaxation ratio of the cartilage transplant, the measured values of the cartilage transplant were divided by the values measured in the reference regions.²²

### RESULTS

#### Subjective Field Strength Comparison

The 7 T MRI was superior in the majority of the sequences regarding overall image quality, the distinction of femoral and acetabular cartilage, and the delineation of the cartilage transplant or remaining cartilage defects (Table 2, Fig. 1). The most prominent improvement gained by the use of the higher field strength was observed in T1 VIBE, where, qualitatively, noise was much less pronounced at 7 T compared with 3 T, resulting in a subjective image quality score of 4.8 ± 0.4 out of a maximum of 5 points. Also the T1 map, where a higher spatial
resolution could be gained at 7 T, was rated clearly superior at the higher field strength regarding all 3 subjective criteria (4.4 ± 0.5, 4.0 ± 1.0, and 3.8 ± 1.0 points), as was the coronal PDw fs sequence (4.6 ± 0.5, 4.7 ± 0.5, and 4.3 ± 0.5 points). The other sequences were superior at 7 T to a lesser extent. A minimal inferiority of 7 T was observed for the overall image quality in PDw TSE (2.9 ± 1.2 points), for the distinction of femoral and acetabular cartilage in DESS (2.9 ± 1.4 points), and for the delineation of the cartilage transplant or remaining cartilage defects in the T2 map (2.8 ± 0.8 points).

**Contrast Ratios**

The contrast ratios between cartilage and joint fluid were clearly higher at 7 T compared with 3 T in DESS (0.41 ± 0.10 vs 0.15 ± 0.09, \(P = 0.02\)) and T1 VIBE (0.42 ± 0.09 vs 0.27 ± 0.08, \(P = 0.03\)). No obvious differences were found for the contrast ratios between cartilage and joint fluid in the PDw sequences (Fig. 2A). The contrast ratios between cartilage and bone were comparable in DESS, T1 VIBE, and the sagittal PDw sequence. In the coronal PD sequence, the contrast was much higher at 7 T compared with 3 T (0.67 ± 0.09 vs 0.44 ± 0.16, \(P = 0.004\); Fig. 2B). The contrast ratios between joint fluid and bone were considerably higher at 7 T compared with 3 T in DESS (0.79 ± 0.08 vs 0.71 ± 0.05, \(P = 0.04\)), T1 VIBE (0.86 ± 0.02 vs 0.76 ± 0.06, \(P = 0.001\)), and the coronal PDw sequence (0.88 ± 0.04 vs 0.75 ± 0.09, \(P < 0.001\)), and comparable in the sagittal PDw sequence (Fig. 2C).

**MOCART Scoring**

The assessment of an adapted MOCART score was possible in every patient at both field strengths. The overall score and its subcriteria showed a total agreement between 7 T and 3 T in 4 patients. In the other 5 patients, the signal intensity of the cartilage transplant was rated higher at 7 T compared with 3 T, resulting in a reduced score at 7 T by 5 to 10 points. All of the patients showed good to very good overall scores (3 T, 60–85 points; 7 T, 55–75 points) without severe filling defects.

**T1 Relaxation Times**

Mean time between contrast agent administration and beginning of the T1 mapping sequence was 86.3 minutes (range, 77–110 minutes) at 7 T and 85.7 minutes (range, 80–99 minutes) at 3 T. When comparing 7 T and 3 T, the difference of this delay time was less than 10 minutes in 8 of 9 patients, and 20 minutes in 1 patient due to a delay of the 7 T scan.

Interreader reliability was excellent both at 7 T (ACT, ICC 0.99/ CV 0.30%; Ref1, ICC 0.99/CV 0.41%; Ref2, ICC 0.98/CV 0.38%; and 3 T (ACT, ICC 0.96/CV 11.0%; Ref1, ICC 0.98/CV 6.2%; Ref2, ICC 0.97/ CV 12.5%). Therefore, only the measurements of the first, more experienced reader were used for further evaluation.

Mean T1 relaxation times at 7 T were 440.7 ± 111.6 milliseconds for the cartilage transplant, 437.8 ± 106.9 milliseconds for the acetabular reference tissue, and 564.3 ± 114.1 milliseconds for the femoral reference tissue. Mean T1 relaxation times at 3 T were 611.3 ± 136.5 milliseconds for the cartilage transplant, 640.1 ± 205.0 milliseconds for the acetabular reference tissue, and 798.8 ± 177.4 milliseconds for the femoral reference tissue. In all 3 regions, the T1 relaxation times measured at 7 T were significantly shorter compared with the T1 relaxation times measured at 3 T (ACT, \(P = 0.008\); Ref1, \(P = 0.007\); Ref2, \(P = 0.04\), Fig. 3). No significant difference could be seen when comparing the T1 relaxation ratios of the cartilage transplant between the field strengths (\(P = 0.23\) and \(P = 0.79\); Fig. 4A).

**T2 Relaxation Times**

Interreader reliability was excellent both at 7 T (ACT, ICC 0.98/ CV 0.32%; Ref1, ICC 0.99/CV 0.41%; Ref2, ICC 0.99/CV 0.38%) and 3 T (ACT, ICC 0.96/CV 11.4%; Ref1, ICC 0.98/CV 6.3%; Ref2, ICC 0.97/ CV 12.5%). Therefore, only the measurements of the first reader were used for further evaluation.

Mean T2 relaxation times at 7 T were 40.0 ± 13.3 milliseconds for the cartilage transplant, 42.7 ± 12.6 milliseconds for the acetabular reference tissue, and 40.0 ± 11.9 milliseconds for the femoral reference tissue. Mean T2 relaxation times at 3 T were 37.3 ± 11.7 milliseconds for the cartilage transplant, 40.2 ± 16.0 milliseconds for the acetabular reference tissue, and 38.3 ± 11.9 milliseconds for the femoral reference tissue. In all 3 regions, the T2 relaxation times measured at 3 T were longer compared with the T2 relaxation times measured at 3 T without statistical significance (ACT, \(P = 0.31\); Ref1, \(P = 0.66\); Ref2, \(P = 0.66\), Fig. 3). No significant difference could be seen when comparing the T2* relaxation ratios of the cartilage transplant between the field strengths (\(P = 0.41\) and \(P = 0.30\); Fig. 4B).

**T2* Relaxation Times**

Interreader reliability was excellent both at 7 T (ACT, ICC 0.99/ CV 0.30%; Ref1, ICC 0.99/CV 4.1%; Ref2, ICC 0.98/CV 8.0%) and 3 T (ACT, ICC 0.96/CV 11.0%; Ref1, ICC 0.98/CV 6.2%; Ref2, ICC 0.97/ CV 12.5%). Therefore, only the measurements of the first reader were used for further evaluation.

Mean T2* relaxation times at 7 T were 10.7 ± 3.0 milliseconds for the cartilage transplant, 13.7 ± 4.0 milliseconds for the acetabular reference tissue, and 13.7 ± 4.3 milliseconds for the femoral reference tissue. Mean T2* relaxation times at 3 T were 16.6 ± 6.8 milliseconds for the cartilage transplant, 19.4 ± 7.6 milliseconds for the acetabular reference tissue, and 20.9 ± 8.0 milliseconds for the femoral reference tissue. In all 3 regions, the T2* relaxation times measured at 7 T were

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**TABLE 2. Mean Values of the Subjective Field Strength Comparison (1 = 3 T Clearly Superior, 2 = 3 T Slightly Superior, 3 = 3 T and 7 Equal, 4 = 7 T Slightly Superior, 5 = 7 T Clearly Superior)**

<table>
<thead>
<tr>
<th></th>
<th>Overall Image Quality</th>
<th>Distinction of Femoral and Acetabular Cartilage</th>
<th>Delineation of Cartilage Transplant or Remaining Cartilage Defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>DES 3D</td>
<td>3.9 ± 1.5*</td>
<td>2.9 ± 1.4</td>
<td>3.2 ± 1.1*</td>
</tr>
<tr>
<td>T1 VIBE 3D</td>
<td>4.8 ± 0.4*</td>
<td>3.8 ± 1.0*</td>
<td>3.4 ± 0.7*</td>
</tr>
<tr>
<td>PD TSE sag</td>
<td>2.9 ± 1.2</td>
<td>3.4 ± 1.0*</td>
<td>3.4 ± 0.9*</td>
</tr>
<tr>
<td>PD TSE fs cor</td>
<td>4.6 ± 0.5*</td>
<td>4.7 ± 0.5*</td>
<td>4.3 ± 0.5*</td>
</tr>
<tr>
<td>T1 map sag</td>
<td>4.4 ± 0.5*</td>
<td>4.0 ± 1.0*</td>
<td>3.8 ± 1.0*</td>
</tr>
<tr>
<td>T2 map sag</td>
<td>3.0 ± 1.2</td>
<td>3.1 ± 0.9*</td>
<td>2.8 ± 0.8</td>
</tr>
<tr>
<td>T2* map sag</td>
<td>3.8 ± 0.7*</td>
<td>3.3 ± 0.7*</td>
<td>3.5 ± 0.7*</td>
</tr>
</tbody>
</table>

* A mean value higher than 3 indicates the superiority of 7 T compared with 3 T and is marked.

DESS indicates dual echo steady state; 3D, 3-dimensional; VIBE, volume interpolated breath-hold examination; PD, proton density; TSE, turbo spin echo; sag, sagittal; fs, fat saturated; cor, coronal.
significantly shorter compared with the T2* relaxation times measured at 3 T (ACT, \( P = 0.003 \); Ref1, \( P = 0.004 \); Ref2, \( P = 0.0003 \); Fig. 3). No significant difference could be seen when comparing the T2* relaxation ratios of the cartilage transplant between the field strengths (\( P = 0.32 \) and \( P = 1.0 \); Fig. 4C).

**DISCUSSION**

This study evaluated morphological and quantitative 7 T MRI sequences for hip imaging in patients after acetabular cartilage transplantation and compared image quality to 3 T MRI. Whereas 7 T has proved its superiority over lower field strengths in several studies for neuroradiological applications,\textsuperscript{23,24} the use of ultrahigh-field systems

![Figures 1 and 2](image.png)
in body imaging is still in its infancy mainly due to the unavailability of commercial RF coils and the inherent technical challenges to overcome B1 inhomogeneities in larger fields of view or in off-center regions. For peripheral joints, comparative studies have already shown superiority over 3 T MRI regarding higher spatial resolution or shorter scan time in the knee and regarding an increase in SNR and CNR in the ankle. In addition, for superficial structures of the musculoskeletal system such as the temporomandibular joint, the local B1+ field and thus the SNR could be improved by the application of high-permittivity dielectric pads. However, imaging the hip remains challenging at ultrahigh fields because of the deep anatomical region and the impossibility to position the joint in the center of the left-right axis of the magnetic field. Until now, early feasibility studies have shown how to overcome technical challenges such as optimization of transmit efficiency and B1 homogenization.

Apart from 2 studies of Chang et al. who both developed a 7 T hip MRI protocol and applied it in patients, no further literature is published dealing with the application of 7 T MRI for the evaluation of hip joint pathologies. The latter author group observed mainly equal image quality at 7 T compared with 3 T, with evidence that ultrahigh field strengths could be advantageous in cartilage imaging. Building on these findings, our study now focused on dedicated hip cartilage imaging at 7 T. Here, in imaging this subtle structure, the superiority over 3 T could clearly be demonstrated in terms of overall image quality, the distinction of femoral and acetabular cartilage, and the delineation of cartilage transplants or remaining cartilage defects, as well as in terms of contrast between joint fluid, cartilage, and bone. We believe that 7 T MRI therefore can add great value to the non-invasive follow-up of patients after cartilage repair surgery. When assessing the MOCART score at 7 T, the higher contrast ratios compared with 3 T have to be taken into account, which can emphasize signal enhancement of the repair tissue and therefore might reduce the overall score. After this study on initial experiences, the clinical relevance of the technical advances of 7 T MRI still needs to be proven in a clinical follow-up study.

To overcome the technical challenges, we included dGEMRIC as well as T2 and T2* mapping as quantitative techniques, dedicated for imaging cartilage vitality. Previous studies discussed the problem of a desire for higher resolution but the undesired accompanying loss of SNR at 3 T. In addition, at 3 T femoral and acetabular cartilage could not always be definitely separated in the quantitative maps. Based on the results of previous volunteer studies, we were able to implement quantitative imaging techniques with high resolution in our 7 T hip imaging protocol with improvements over 3 T especially for T1 mapping.

A concern in our study is the comparison of T1, T2, and T2* relaxation times between the field strengths. Contrary to the expectation from basic physics and in vitro studies, the absolute T1 relaxation times measured at 7 T were shorter compared with those measured at 3 T. The same effect had been observed before for the T2* relaxation times. Novel T2 mapping techniques based on a triple-echo steady-state approach might overcome this B1 sensitivity of our measurements, but also underlining the importance of calculating intraindividual ratios.

Despite the discrepancies in the absolute values, the relaxation ratios of T1, T2, and T2* were highly comparable between the field strengths, indicating the accuracy of our measurements, but also underlining the importance of calculating intraindividual ratios. Our study had several limitations. First of all, the number of 9 patients is limited, aggravating the comparison of the quantitative measurements due to interindividual differences. However, due to the technical challenges at 7 T with a time-consuming setup, the wider...
range of potential contraindications to ultrahigh fields or to the application of gadolinium in double dose twice, the lower acceptance by patients to take part in additional research scans, and the limited number of patients treated with the reported method, a much larger patient cohort would require immensely more dedication. Thus, we decided to publish these data as initial results to motivate others to plan prospective studies. Second, the protocol used was dedicated to assess hip cartilage. The evaluation of surrounding structures such as muscles or tendons is not the aim of the proposed protocol, and the coverage of the imaging sequences is thus limited, and also a comparison to the contralateral side was not included. Therefore, pathologies outside the joint cannot be sufficiently evaluated with the proposed protocol. Third, although we tried to keep the protocols at 7 T and 3 T as equal as possible, especially, the comparison of the coronal PDw TSE with the PDw SPACE sequence has to be interpreted with caution. However, as PDw SPACE has proved its superiority over 2-dimensional PDw fs sequences in several musculoskeletal applications\textsuperscript{11–43} but was mainly inferior to 7 T in our study, one can indirectly conclude that our coronal 7 T PDw fs sequence is superior to 2-dimensional PDw sequences at 3 T as well.

Another limitation of the protocol is the lack of a precontrast T1 mapping. Although previous studies have shown the correlation between precontrast and postcontrast T1 relaxation times,\textsuperscript{1,44–46} the question if precontrast T1 mapping can be omitted in patients after cartilage repair surgery is still discussed controversially. In this study on initial experiences, we decided to omit the time-consuming precontrast T1 mapping. In further studies focusing on a correlation of absolute T1 values with clinical evaluations, the necessity of precontrast T1 mapping should be discussed critically, as well as the delay between contrast agent administration and postcontrast T1 mapping, which was with nearly 90 minutes in our study relatively long.\textsuperscript{46,47} A further limitation is the in consensus rating in our study, which is inferior to the rating of 2 raters independently. However, we decided on the consensus mode for the subjective ratings for 2 reasons. On the one hand, although we already had some experience with hip and hip cartilage imaging at 7 T, we still consider our experience in rating such images as limited and therefore cannot rely on standards regarding image quality. On other hand, due to the small number of patients, the calculation of interobserver reliabilities for the subjective ratings would not have been conclusive. The different algorithms used for the calculation of the T1 relaxation time maps at 3 T and 7 T are another limitation of this study. At 3 T, the B1 correction was done automatically pixel-wise before generating the relaxation time map, whereas at 7 T, the B1 correction was done only globally over the joint by adjusting the RF transmit power from flip angle maps obtained with the DREAM technique. Obtaining such B1 or flip angle maps in the body at 7 T is highly challenging and certainly comes with additional uncertainties.\textsuperscript{47} This might have furthermore biased the comparability of the T1 relaxation times. Hence, data from other sites would be highly desirable for comparison reasons.

In conclusion, this study shows the feasibility of morphological and quantitative 7 T hip MRI in patients after acetabular cartilage transplantation and its predominant superiority regarding image quality, assessment of cartilage transplants, and contrast over 3 T.

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References
