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MUSCULOSKELETAL

Biochemical (T2, T2* and magnetisation transfer ratio) MRI of knee cartilage: feasibility at ultra-high field (7T) compared with high field (3T) strength

Goetz H. Welsch · Sebastian Apprich · Stefan Zbyn · Tallal C. Mamisch · Vladimir Mlynarik · Klaus Scheffler · Oliver Bieri · Siegfried Trattnig

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Abstract
Objective This study compares the performance and the reproducibility of quantitative T2, T2* and the magnetisation transfer ratio (MTR) of articular cartilage at 7T and 3T.
Methods Axial MRI of the patella was performed in 17 knees of healthy volunteers (25.8±5.7 years) at 3T and 7T using a comparable surface coil and whole-body MR systems from the same vendor, side-by-side. Thirteen knee joints were assessed once, and four knee joints were measured three times to assess reproducibility. T2 relaxation was prepared by a multi-echo, spin-echo sequence and T2* relaxation by a multi-echo, gradient-echo sequence. MTR was based on a magnetisation transfer-sensitized, steady-state free precession approach. Statistical analysis-of-variance and coefficient-of-variation (CV) were prepared.
Results For T2 and T2*, global values were significantly lower at 7T compared with 3T; the zonal evaluation revealed significantly less pronounced stratification at 7T ($p<0.05$). MTR provided higher values at 7T ($p<0.05$). CV, indicating reproducibility, showed slightly lower values at 7T, but only for T2 and T2*.
Conclusion Although lower T2 and T2* relaxation times were expected at 7T, the differences in stratification between the field strengths were reported for the first time. The assessment of MT is feasible at 7T, but requires further investigation.

Keywords T2 · T2* · Magnetisation transfer · Cartilage · 3 Tesla · 7 Tesla

G. H. Welsch (✉) · S. Apprich · S. Zbyn · T. C. Mamisch · S. Trattnig
MR Center, Department of Radiology,
Medical University of Vienna,
Lazarettgasse 14,
Vienna A-1090, Austria
e-mail: welsch@bwh.harvard.edu

G. H. Welsch
Department of Trauma Surgery, University of Erlangen,
Erlangen, Germany

T. C. Mamisch
Department of Orthopedic Surgery, University of Berne,
Berne, Switzerland

V. Mlynarik
Laboratory of functional and metabolic imaging, Ecole Polytechnique Federale de Lausanne,
Lausanne, Switzerland

K. Scheffler · O. Bieri
Division of Radiological Physics, Institute of Radiology,
University Hospital Basel,
Basel, Switzerland

Introduction

Cartilage lesions that subsequently develop osteoarthritis (OA) are the most common musculoskeletal diseases affecting millions of people [1]. In the evaluation of articular cartilage, cartilage repair and OA, biochemical magnetic resonance imaging (MRI) plays an important role. Different biochemical methods have been exploited for their potential use at 1.5 Tesla and 3.0 Tesla (3T) in various studies, and, recently, in clinical routine protocols, as well [2, 3]. Advances in coil technology and high- to ultra-high-field systems (3T to 7.0 Tesla (7T) and above) significantly improve the ability of biochemical imaging to diagnose cartilage disorders at an earlier stage than morphological imaging can provide [4]. While delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) focuses on the

visualisation of the glycosaminoglycan content of cartilage, techniques such as T2 and T2* relaxation time mapping and magnetisation transfer (MT) imaging are likely to be strongly influenced by the orientational behaviour of collagen, the collagen content and tissue hydration [5–7]. Initial results with T2 and T2* relaxation time mapping have already been presented at ultra-high field strengths [8, 9], whereas a recently described magnetisation transfer-sensitised, steady-state free precession (SSFP)-based approach [10] was developed to generate MT contrast at high field strengths [11]. However, to our knowledge, no direct in vivo comparison of biochemical MRI methodologies at high and ultra-high field strengths is available.

The aim of this study was to compare the performance and the reproducibility of T2, T2* and MTR mapping of articular cartilage at 3T and 7T.

Materials and methods

Volunteers

Ethical approval for this study was given by our University ethics commission, and written, informed consent was obtained from all volunteers before enrolment in the study.

Axial MRI of the patella was performed in 17 knee joints of healthy volunteers (mean age, 25.8±5.7 years) with no known musculoskeletal disease and no history of trauma or pain prospectively. Thirteen knee joints in eight volunteers were measured once (7 right, 6 left knees; 4 female, 9 male), four knee joints in four volunteers (2 right, 2 left knees; all male) were measured three times on different days to assess reproducibility. All volunteers underwent imaging after at least half an hour of rest to avoid changes in biochemical T2, T2*, or MTR values because of different loading before MR measurement [12]. The volunteers who were included three times for reproducibility measurements underwent imaging at the same time of day; the three different MR measurements were performed over a period of no more than 10 days.

Image acquisition

Magnetic resonance imaging was performed on a 3T whole-body system (Tim-Trio, Siemens Healthcare, Erlangen, Germany) and a side-by-side 7T whole-body system (Magnetom 7 Tesla, Siemens Healthcare, Erlangen, Germany). Comparable surface coils (diameter 10 cm) (Rapid, Rimpar, Germany) were used at 3T (^{1}H 123 MHz) and at 7T (^{1}H 297 MHz). Half the patients started with the 3T MR protocol followed by the 7T MR protocol, and the other half began with the 7T MR protocol followed by the 3T protocol.

The MR protocol consisted of an axial, high-resolution, proton-density, turbo spin-echo sequence (PD-TSE) to morphologically evaluate cartilage and exclude volunteers with possible morphological alterations. For T2 relaxation, an axial, multi-echo, spin-echo (me-SE) sequence (six echoes) was performed, whereas T2* relaxation was obtained by an axial, multi-echo gradient-echo (me-GRE) sequence (six echoes). MTR images were calculated from MT-weighted and non-MT-weighted images of an axial, magnetisation transfer-sensitised, steady-state free precession sequence, as described in detail elsewhere [10].

Most sequence parameters were set identically for both field strengths to ensure comparability, although all sequences must be adapted to ultra-high-field MRI in future approaches.

For me-SE-T2 mapping, to minimise T1 weighting, as well as to reduce application time, the repetition time (TR) was set as TR≥T1. This resulted in a TR of 1200 ms for T2 mapping at 3T, and, due to the scarce available data for T2 mapping at 7T, in two SE-T2 mapping sequences with different repetition times (TR_1=1600 ms and TR_2=2000 ms). Other me-SE parameters were: echo times TE=13.8 ms, 27.6 ms, 41.4 ms, 55.2 ms, 69 ms and 82.8 ms; a flip-angle (FA) of 180°; and a field-of-view (FoV) of 120×120 mm^2 with 256×256 matrix size, yielding a 0.47×0.47 mm^2 resolution . A bandwidth of 230 Hz/pixel was used, no fat saturation, with 12 slices (3 mm thickness), and the total acquisition times were 5:11 (TR1200ms), 6:54 (TR1600ms), and 8:36 min (TR2000ms), respectively.

The me-GRE-T2* measurements were conducted with a TR of 600 ms at 3T and a TR of 800 ms at 7T (adapted as ½ TR of the me-SE-T2 sequence), with TEs of 4.2 ms, 11.3 ms, 18.5 ms, 25.6 ms, 32.7 ms, and 39.9 ms and an FA of 60°. Essentially identical FoV, matrix, slice thickness, and voxel size were used as with the me-SE T2 acquisition. The bandwidth was 260 Hz/pixel, no fat saturation, 12 slices, and the total acquisition time was 2:35 (TR600) and 3:26 min (TR800), respectively.

The MT sequence was prepared with a TR of 5.0 ms, a TE of 2.0 ms and an FA of up to 40° at 3T, and with a TR of 5.03 ms, a TE of 2.52 ms, and an FA of up to 40° at 7T. The FA was prepared as high as possible in accordance with the applied specific absorption rate. The resolution parameters were again identical to the T2 and T2* sequences. The bandwidth was 425 Hz/pixel at 3T and 558 Hz/pixel at 7T, no fat saturation, with 12 slices, and the total acquisition time was 1:54 min at 3T and 2:09 min at 7T. MT images were acquired with a short 0.27 ms RF pulse duration and a long 2.7 ms RF pulse duration.

Morphological images were acquired using a PD-TSE sequence with a TR of 2400 ms at 3T and a TR of 4000 at 7T, a TE of 36 ms, and a flip angle of 160°. FoV was 120×120mm, the pixel matrix was 512×512, and the voxel size

was 0.23×0.23×2mm. The bandwidth was 244 Hz/pixel, and total imaging time for 12 slices was 3:28 (TR2400) and 4:22 (TR4000), respectively.

Image analysis

T2 and T2* maps were obtained in-line using a pixel-wise, non-negative, least-squares (NNLS) mono-exponential fitting analysis (with the first echo included). MTR maps were also calculated in-line (from the steady-state signal intensities (S) according to $MTR=(S(MT_{none}) - S(MT_{sat}))/S(MT_{none})$; expressed in percentage units [%]). Exemplary T2, T2* and MTR maps at both field strengths are presented in Figs. 1, 2 and 3.

Region of interest (ROI) analyses were manually performed for evaluation. ROIs were drawn by an orthopaedic surgeon with a special interest in musculoskeletal MR imaging (10 years'experience), in consensus with a young radiologist (2 years' experience), under the supervision of an experienced senior musculoskeletal radiologist (25 years' experience). The ROIs had to cover the full thickness of articular cartilage of the whole patella; in addition, a zonal ROI evaluation was performed on equal-sized deep and superficial ROIs. Three consecutive slices in the middle of the patella were assessed. The mean number of pixels for each of the different zones was 1147±607. The analysis of mean (full-thickness) and zonal (deep and superficial) T2, T2* and MTR values was performed based on 17 knee joints (13 knee joints with one MRI and the first MRI of the four knee joints assessed three times for reproducibility). The zonal variation was also provided as a percentage increase between deep and superficial cartilage layers: ROIsuperficial–ROIdeep)/ROIsuperficial*100.

Furthermore intra-observer and inter-observer reproducibility was evaluated based on the assessment of 10 knee joints with one MRI. For the intra-observer reliability, the orthopaedic imaging expert re-analyzed the images after more than 3 months in a randomized order. For inter-observer reliability, all three observers with different experience levels (25 years, 10 years and 2 years) assessed the images independently.

The coefficient of variation (CV) was performed for T2, T2* and MTR based on the three repeated measurements from four volunteers as a marker of reproducibility.

Additionally signal-to-noise ratio (SNR) was assessed based on the evaluation of 10 knee joints with one MRI. The measurements were performed by the orthopaedic surgeon with a special interest in musculoskeletal MR imaging (10 years'experience), in consensus with the young radiologist (2 years' experience). The SNR was assessed as the mean signal intensity of patellar cartilage divided by the standard deviation of the background regions (noise). The signal intensity of cartilage and the background regions were measured three times for each sequence with each system (3T and 7T). As provided above, noise was defined as the standard deviation of signal intensity in air outside of the extremity. The SNR assessment was performed for the biochemical T2 and T2* sequences (all 6 echoes) and the MT sequence (MT weighted and MT free).

Statistical analysis

Statistical evaluation was performed for all mean and zonal T2, T2* and MTR values. To account for multiple measurements within one volunteer, univariate ANOVA with random factors and post-hoc tests, according to Games-Howell, was applied for quantitative analysis. The intra-observer and inter-observer reproducibility was assessed using intraclass correlation coefficient (ICC). The reproducibility is given for each volunteer as a coefficient of variation (CV, given in%), averaged over all volunteers, and was interpreted as a grade of precision by apportionment of the standard deviation relating to the mean. For statistical analysis, SPSS version 17.0 (SPSS Institute, Chicago, IL, USA) for Windows (Microsoft, Redmond, WA, USA) was used, and a P value of less than 0.05 was considered to be statistically significant.

Results

Morphological MRI revealed healthy articular cartilage and no visible alterations in the patellofemoral cartilage in all knee joints.

T2 relaxation

Mean T2 values (ms) at 3T (44.1±8.4) were significantly longer compared with those at 7T (41.8±5.5) ($p=0.043$). The zonal evaluation revealed no significant differences between 3T and 7T for the deep cartilage layer (3T: 32.7±6.5; 7T: 35.1±5.9; $p=0.154$); however, significantly higher values were observed for the superficial cartilage layer at 3T compared with 7T (3T: 55.6±11.5; 7T: 48.4±6.5; $p<0.001$). The given T2 values at 7T were assessed with a TR of 1600 ms and showed no difference from the T2 values assessed with a TR of 2000 ms (mean: 42.2±4.7 ($p=0.171$; deep: 35.9±5.1 ($p=0.365$); superficial: 48.5±5.7 ($p=0.340$).

The zonal evaluation revealed a highly significant stratification: an increase in T2 between the deep and the superficial cartilage layer was found for all evaluations ($p<0.001$), but was significantly more pronounced at 3T (41.2%) compared with 7T (27.5%) ($p<0.001$). The zonal evaluation is depicted in Fig. 4a.

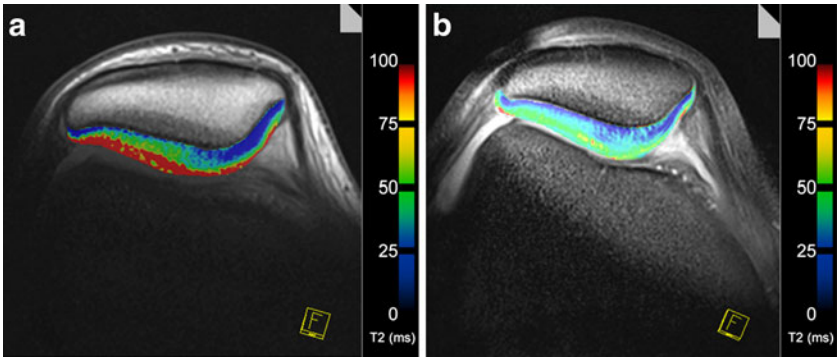

Fig. 1 Axial, multi-echo spin-echo T2 mapping at 3T **a** and 7T **b**. For T2 shorter relaxation times are visible at 7T compared with 3T. When revealing the zonal increase in T2 values from the subchondral border to the cartilage surface, this stratification is less pronounced at 7T compared with 3T

T2* relaxation

Mean as well as zonal T2* relaxation times (ms) were significantly higher at 3T (mean: 22.2±4.3; deep: 17.6±3.7; superficial: 26.9±5.4) compared with 7T (mean: 18.3±4.9; deep: 15.5±3.7; superficial: 21.0±4.5) ($p<0.001$).

With respect to the zonal stratification, comparable to T2 relaxation time mapping, both evaluations, at 3T and at 7T, revealed a significant increase in T2* values from deep to superficial ($p<0.001$). Likewise, the zonal increase in T2* from deep to superficial cartilage was significantly more pronounced at 3T (34.6%) compared with 7T (26.2%) ($p<0.001$) (Fig. 4b).

Magnetisation transfer contrast

Magnetisation transfer ratio values were found to be significantly lower at 3T (mean: 27.6±3.8; deep: 28.0±3.8; superficial: 27.3±3.3) compared with 7T (mean: 35.5±5.2; deep: 33.2±5.2; superficial: 37.7±5.6) for both the mean as well as the zonal evaluation ($p<0.001$). A significant stratification between deep and superficial cartilage layers could not be assessed at 3T ($p=0.074$), but was visible at 7T ($p<0.001$). Furthermore, a zonal evaluation revealed significant differences between 3T (-2.6%) and 7T (11.9%) ($p<0.001$). The zonal results are presented in Fig. 4c.

Intra- and inter- observer reproducibility

The ICC for the inter-observer reproducibility showed to be slightly higher at 3T compared to 7T. For T2 and T2*, the evaluation of the deep layer revealed slightly lower results compared to the superficial layer or the evaluation of the full-thickness (mean) cartilage values. ICCs of T2 relaxation time measurements were 0.947 (mean), 0.893 (deep) and 0.945 (superficial) at 3T and 0.910 (mean), 0.877 (deep) and 0.901 (superficial) at 7T. For T2*, ICCs were 0.903 (mean), 0.875 (deep) and 0.922 (superficial) at 3T and 0.875 (mean), 0.842 (deep) and 0.887 (superficial) at 7T. The ICCs for the MT evaluation were 0.908 (mean), 0.916 (deep) and 0.845 (superficial) for 3T and 0.844 (mean), 0.808 (deep) and 0.845 (superficial) at 7T. The ICCs for the intra-observer reproducibility were overall comparable to the inter-observer results, however in between 0.002 and 0.065 higher.

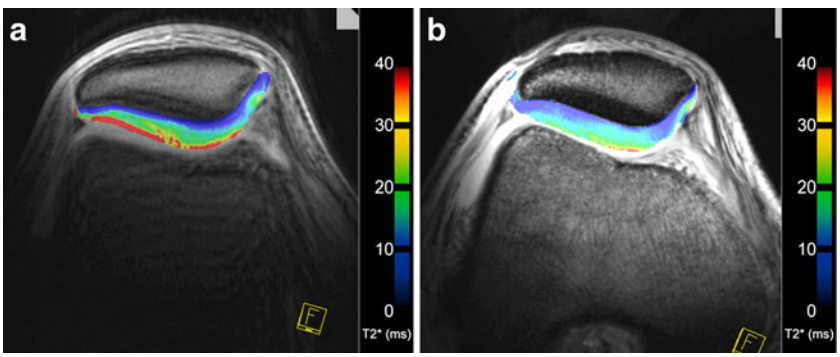

Fig. 2 Axial multi-echo gradient-echo T2* mapping at 3T **a** and 7T **b** of the same healthy volunteer as presented in Fig. 1. Comparable to multi-echo, spin-echo T2 mapping, relaxation times appear to be shorter at 7T compared with 3T and the zonal stratification is less pronounced at 7T compared with 3T

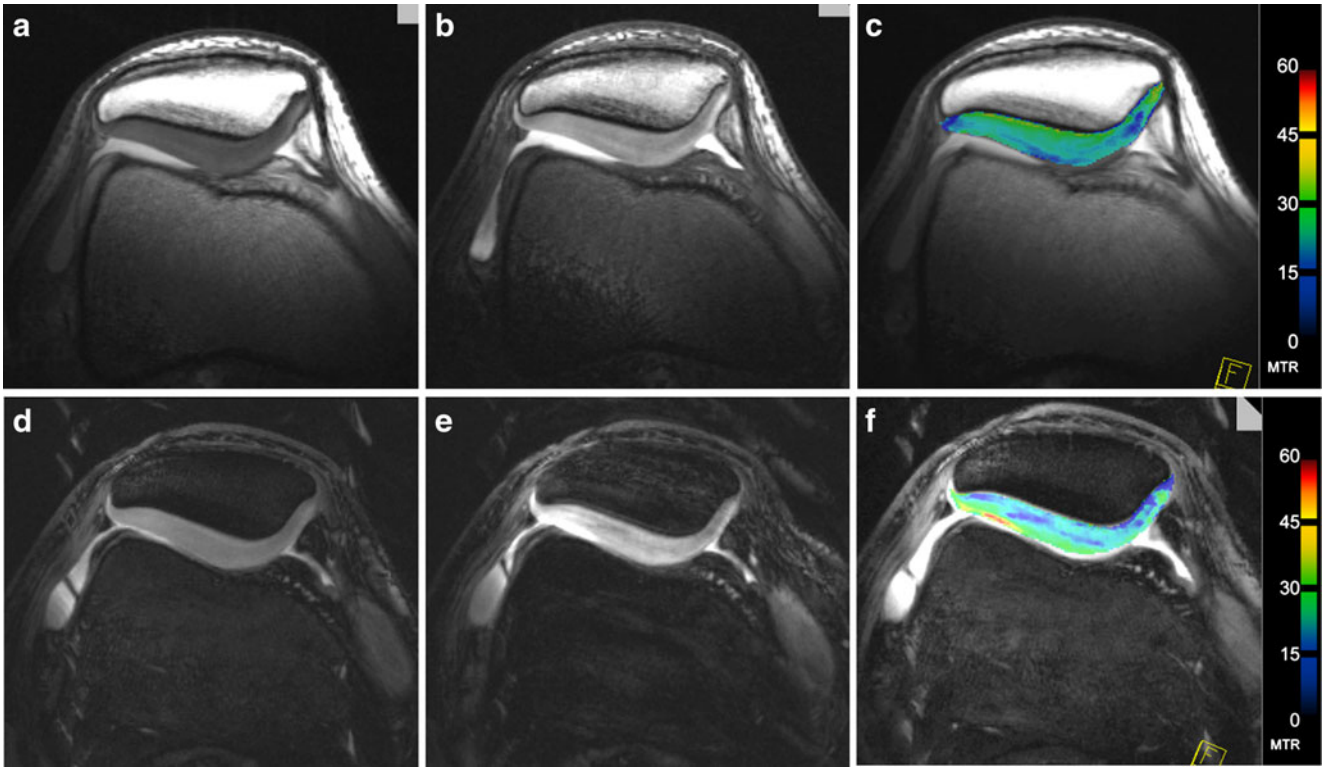

Fig. 3 Axial magnetisation transfer images based on magnetisation transfer-sensitised, steady-state free precession at 3T **a**-**c** and 7T **d**-**f** of the same healthy volunteer as depicted in Fig. 1. The magnetisation transfer ratio (MTR) **c**, **f** is calculated from the MT saturated **a**, **d** and the MT free **b**, **e** images

Coefficients of variation

The CV for T2 was slightly higher at 3T (mean: 8.7%; deep: 9.5%; superficial 8.6%) compared with 7T (mean: 7.2%; deep 8.2%; superficial 7.2%). Similarly, the CV for T2* was also slightly higher at 3T (mean: 7.8%; deep: 8.8%; superficial: 8.1%) compared with 7T (mean: 6.8%; deep: 7.9%; superficial: 6.9%). The CV of MTR provided lower results at 3T (mean: 9.2%; deep: 9.5%; superficial: 9.4%), but was comparable to 7T (mean: 10.8%; deep: 11.4%; superficial: 10.6%).

Signal-to-noise ratio

The SNR as assessed for the biochemical T2, T2* and MT sequences is provided in Table 1. Throughout the measurements, SNR for 7T was higher compared to 3T ($p<0.05$).

Discussion

In the present study, biochemical imaging techniques were compared in vivo, side-by-side, at 3T and 7T. Special care was taken to perform measurements with a comparable surface coil. However, for future approaches, further sequence optimisation, especially for MT, may be beneficial. Mean (full-thickness) T2 and T2* relaxation times were shorter at 7T compared with 3T, as expected; however, MT contrast was increased at 7T compared with 3T. Overall, the zonal evaluation seemed to supply even more interesting results in the comparison of both field strengths.

This in vivo study clearly demonstrates the differences in the zonal T2 behaviour at 3T and 7T. Pakin et al. [8] described T2 mapping at 7T, but no zonal analysis was performed. The basis of the stratification of T2 values becomes obvious when considering in vitro studies on articular cartilage, suggesting that the appearance of T2 relaxation times is strongly influenced by the anisotropic arrangement of the collagen fibres and by their orientation to the main magnetic field [13–15]. The importance of considering the stratification of T2 values from the subchondral border to the cartilage surface has already been noted by many in vivo studies [16–19]. Smith and co-workers [17] reported a zonal stratification in the patella, with a maximum of 33% at 3 Tesla, which falls between our findings at 3T and 7T. In the present study, it is notable that the stratification of T2 values was significantly more pronounced at 3T compared with 7T.Theoretically, for a regular exponential decay of magnetization with the echo time, T2 should be either B0-independent (assuming only

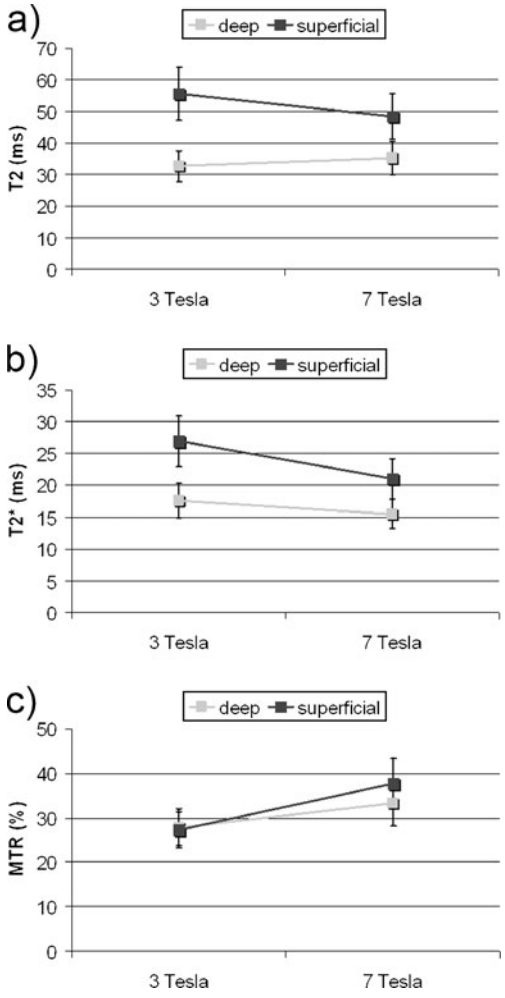

Fig. 4 Zonal (deep and superficial) T2 **a**, T2* **b** and MTR **c** values between 3T and 7T. For T2 and T2*, at both field strengths, a zonal increase from deep to superficial becomes visible. This stratification is less pronounced at 7T compared with 3T. For MTR, lower values are visible at 3T compared with 7T, whereas a zonal increase from deep to superficial is only visible at 7T

dipolar relaxation mechanism) or should decrease with increasing B0 (due to diffusion of water molecules in susceptibility-induced field inhomogeneities, which are proportional to B0, and/or due to chemical exchange of water protons with other acidic protons, which increases with B0). The magnetisation decay in cartilage is, however, non-exponential (roughly bi-exponential) with a short, strongly B0-dependent component, and with a longer component. In the deep layer, residual magnetisation of the short T2 component can still contribute at 3T for the first echo time used, whereas no significant contribution is expected from the T2 shortening with increasing field strength at 7T. As a result, the measured apparent T2 is shorter at 3T compared with 7T. In the superficial layer, because of random fibre orientation, the short T2 component is probably too small to substantially affect the normal, expected exponential decay [20, 21]. Remarkably the T2 values were even longer in the deep layer at 7T (35.1 ms) compared to 3T (32.7 ms). Hence when the T2 values are measured with the minimum TE of 13.8 ms, the short magnetization component in the deep layer can still be present (unrelaxed) at this TE at 3 Tesla, whereas it is already fully relaxed at 7 Tesla. As a result, the measured T2 at 3 Tesla is "apparently" shorter at 3T than at 7 Tesla.

A further source of error, especially for the relaxation times of the deep cartilage layer, might be the effect of chemical shift artefact on quantification, especially at 7T. As due to a more stable signal at both field strengths, no fat saturation was applied for T2 and T2* mapping, the measured zonal variation might be influenced. Also when looking at the reproducibility assessment (ICC and CV), the evaluation of the deep cartilage layer shows slightly inferior results compared to the superficial cartilage layer.Differences in the zonal variation between the field strengths could also be detected for T2*. Very recently, T2* has gained increased interest [22, 23], as 3D me-GRE provides some advantages, compared with standard me-SE T2. It has been described, in a comparison with me-SE-T2, in an initial study at ultra-high field strengths [9], but no direct comparison between 3T and 7T is available. The present results indicate similar behaviour for the mean as well as zonal T2* and T2 with regard to magnetic field strength. For both biochemical parameters, mean values decrease with increasing field strength; however, the biochemical

Table 1 Signal-to-noise ratio (SNR) of the biochemical T2, T2* and magnetization transfer (MT) MR measurements at 3T and 7T. T2 and T2* as assessed for the different echo times (TE); MT is provided for the MT and the free images

T2	TE=13,8 ms	TE=27,6 ms	TE=41,4 ms	TE=55,2 ms	TE=69,0 ms	TE=82,2 ms
3T mean	48,1	52,9	35,2	28,2	21,1	17,1
7T mean	67,4	69,9	48,7	39,1	28,8	20,1
T2*	TE=4,2 ms	TE=27,6 ms	TE=41,4 ms	TE=55,2 ms	TE=69,0 ms	TE=82,2 ms
3T mean	111,7	90,4	74,4	60,1	47,3	38,8
7T mean	159,8	141,4	111,4	99,6	71,7	51,2
MT	MT weighted	MT none				
3T mean	54,9	77,9				
7T mean	66,8	96,6				

content of articular cartilage, as detected by T2*, shows differences from T2 [23] that require further validation at both field strengths. The presence of a zonal variation in T2* is thus not seen as proof that T2 and T2* visualise the same biochemical composition of articular cartilage. For example, the proteoglycan concentration is also known to show different quantities from deep to superficial cartilage [24], and the zonal T2* dependence may be caused not only by the collagenous architecture, but also by macromolecular differences and orientation.

Reproducibility, with regard to the coefficient of variation, reveals a slightly better result for both T2 and T2* at 7T compared with 3T. The intra- and inter-observer reproducibility measurements however showed slightly better results for the 3T MR measurements. To date, only a few other studies have been published on the reproducibility of biochemical MRI, and further investigations are needed. Quaia et al. using a fast T2 mapping approach, found higher CVs than those observed in our study; however that study was performed at 1.5 Tesla [25]. Comparable values were described by Hannila et al. which found CVs in between 5.3% and 11% for T2 mapping at 1.5T [26]. Mosher and co-workers report on significantly reduced CV (down to 3%) by using a positioning device for the knee joint at 3 Tesla [27]. Another study by Pai et al. showed a CV of about 5% for quantitative T2 of cartilage in vivo. Concerning the intra-class correlation coefficients, Bittersohl et al. [22] reported similarresults, compared to the present study, for T2* mapping in the hip, ranging in between 0.826 and 0.954.

When looking at the assessed signal-to-noise ratios, as expected, there seem to be higher values for 7T compared to 3T. This however does not lead to a clearly better reproducibility, which might still be due to limitations based on the lack of optimization of post-processing algorithms at ultra high fields.

No study could be found that addressed the reproducibility of MT contrast in articular cartilage. In the present approach, the results of both, the ICC and the CV, revealed a slightly better reproducibility at 3T compared with 7T. It is well-known that several factors influence MT contrast, such as instrumental variation, sequence parameters, and, especially, B0 and B1 effects. Although more and more 7T systems are now commercially available, problems with ultra-high-field systems, such as optimisation of B1 homogeneity, are still a matter of current research. It is, therefore, not unexpected that, especially with MT, higher variation is observed compared with sophisticated, mature clinical 3T systems.

Magnetisation transfer ratio values were shown to be higher at 7T, compared with 3T, in our study. In general, the measured MTR depends on the efficiency of saturation of the bound proton pool and on the relaxation properties of mobile protons: with increasing T1 or increasing T2, an increase in MT can be expected with MT-sensitised SSFP. With increasing field strength, however, T2 decreases while T1 increases, which may counterbalance their effects on the MT contrast achieved with SSFP. One major issue with 7T is the prediction of RF power deposition and B1 homogeneity, which can have a major impact on the achievable level of MT contrast. One available study with a comparable MT approach, using MT-sensitised SSFP for healthy cartilage sites of the femoral condyles in patients after cartilage repair of the knee joint [11], showed elevated MTR values at 3T compared with those in our study. The biochemical cartilage composition, however, differs between the patella and the femoral condyles [28], and no healthy volunteers were included in that study [11]. The zonal MTR evaluation provided no clear direction for assessment between the deep and the superficial cartilage layer at 3T, however, suggesting an increase at 7T that must be assessed in more detail in upcoming studies.

The main limitation of the present study is the lack of "real" ultra-high-field sequences. Sequence parameters were simply adapted for both field strengths to gain comparability, such as the use of a different TR for mSE T2 measurements because of the known increase in T1 with increasing field strength. Other parameters, however, must be optimised in future approaches, and new biochemical sequences may have to be implemented for their use at ultra-high field strengths. The used TR might nevertheless not be long enough to minimize a possible T1 effect. In recent articles the used TR at 3T ranges in between 1200 ms and 2700 ms [27–30]. In addition, only healthy volunteers were included and no gold standard was available. The zonal T2 and T2* results, particularly in their comparison between both field strengths, as well as MT contrast at ultra-high field strengths, require further validation. With respect to the assessed longer relaxation times in the deep layer at 7T compared to 3T, the longest TE (for both, T2 and T2* mapping) might be to long for the cartilage in the deep layer which might produce possible bias during fitting. Furthermore the effect of chemical shift artefact on quantification, especially at 7T has to be seen as a limitation as no fat saturation was applied.

In summary, the present study presents an initial approach to directly comparing in vivo biochemical cartilage MRI sequences at 3T and 7T using comparable coils and MR systems from the same vendor. Our results demonstrate, for the first time, the feasibility of T2 mapping, T2* mapping and MTR at both field strengths with an acceptable reproducibility. Furthermore, the ability and the need for a zonal evaluation of articular cartilage could be illustrated for all sequences and at both field strengths.

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