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Krijbolder, D.I.; Verstappen, M.; Wouters, F.; Lard, L.R.; Buck, P.D.M. de; Veris-van Dieren, J.J.; ... ; Helm-van Mil, A.H.M. van der

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Comparison between 1.5T and 3.0T MRI: both field strengths sensitively detect subclinical inflammation of hand and forefoot in patients with arthralgia

DI Krijbolder[1], M Verstappen[1], F Wouters[1], LR Lard[2], PDM de Buck[3], JJ Veris-van Dieren[4], JL Bloem[5], M Reijnierse[5], AHM van der Helm-van Mil[1,6]

[1]Department of Rheumatology, Leiden University Medical Center, Leiden, The Netherlands
[2]Department of Rheumatology, LangeLand Hospital, Zoetermeer, The Netherlands
[3]Department of Rheumatology, Haaglanden Medical Center, The Hague, The Netherlands
[4]Department of Rheumatology, Reumazorg Zuid West Nederland, Goes, The Netherlands
[5]Department of Radiology, Leiden University Medical Center, Leiden, The Netherlands
[6]Department of Rheumatology, Erasmus Medical Center, Rotterdam, The Netherlands

Objective: Magnetic resonance imaging (MRI) of small joints sensitively detects inflammation. This inflammation, and tenosynovitis in particular, has been shown to predict rheumatoid arthritis (RA) development in arthralgia patients. These data have predominantly been acquired on 1.0–1.5 T MRI. However, 3.0 T is now commonly used in practice. Evidence on the comparability of these field strengths is scarce and has never included subtle inflammation in arthralgia patients or tenosynovitis. Therefore, we assessed the comparability of 1.5 T and 3.0 T in detecting subclinical inflammation in arthralgia patients.
Method: A total of 2968 locations (joints, bones, tendon sheaths) in the hands and forefeet of 28 patients with small-joint arthralgia, at risk for RA, were imaged on both 1.5 and 3.0 T MRI. Two blinded readers independently scored erosions, osteitis, synovitis, and tenosynovitis, in line with the Rheumatoid Arthritis Magnetic Resonance Imaging Score (RAMRIS). Features were summed into inflammation (osteitis, synovitis, tenosynovitis) and RAMRIS (inflammation and erosions). Agreement was assessed with intraclass correlation coefficients (ICCs) for continuous scores and after dichotomization into presence or absence of inflammation, on patient and location levels.
Results: Interreader ICCs were excellent (> 0.90). Comparing 1.5 and 3.0 T revealed an ICC of 0.90 for inflammation and RAMRIS. ICCs for individual inflammation features were: tenosynovitis 0.87 (95% confidence interval 0.74–0.94), synovitis 0.65 (0.24–0.84), and osteitis 0.96 (0.91–0.98). Agreement was 83% for inflammation and 89% for RAMRIS. Analyses on the location level showed similar results.
Conclusion: Agreement on subclinical inflammation between 1.5 T and 3.0 T was excellent. Although synovitis scores were slightly different, synovitis often occurs simultaneously with other inflammatory signs, suggesting that scientific results on the predictive value of MRI-detected inflammation for RA, obtained on 1.5 T MRI, can be generalized to 3.0 T MRI.

Magnetic resonance imaging (MRI) plays a prominent role in risk prediction for the development of rheumatoid arthritis (RA), especially in the arthralgia phase when clinical arthritis cannot yet be detected and joint inflammation is subclinical (1). To standardize the measurement of MRI inflammation, the Outcomes Measures in Rheumatology (OMERACT) working group on RA developed the Rheumatoid Arthritis Magnetic Resonance Imaging Scoring system (RAMRIS) (2). Of the different RAMRIS inflammatory features (synovitis, osteitis, and tenosynovitis), tenosynovitis has the highest accuracy for clinical arthritis development and most strongly underlies the characteristic symptoms (3, 4). In contrast, evaluating MRI for erosions in addition to subclinical inflammation does not provide added predictive value for the development of inflammatory arthritis (5).

Research on the predictive ability of MRI in arthralgia patients is predominantly performed on dedicated extremity 1.0 –1.5 T MRI. However, these types of MRI systems are gradually being replaced, mostly by large-bore 3.0 T MRI. As a result, 3.0 T MRI will often be used in future RA research and clinical practice. It has been shown previously that dedicated extremity 1.5 T MRI and large-bore 1.5 T

Doortje I Krijbolder, Department of Rheumatology, Leiden University Medical Center, PO Box 9600, Leiden 2300 RC, The Netherlands. E-mail: d.i.krijbolder@lumc.nl

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MRI are equivalent (6). However, the scientific evidence on the comparability of 1.5 T dedicated extremity and 3.0 T large-bore MRI is scarce.

So far, most studies comparing field strengths have focused on evaluating dedicated extremity low-field (0.2 T) to mid-field MRI (1.0–3.0 T) (7–9). MRI inflammation on large-bore 1.5 T was compared to large-bore 3.0 T in three studies, two of which studied only one RAMRIS feature (osteitis and synovitis, respectively) without contrast enhancement on both field strengths, hence limiting the ability to depict synovitis (10, 11). The third study compared 1.5 T and 3.0 T MRI (both contrast enhanced) in 17 established RA patients, but did not include tenosynovitis (12).

Within this limited evidence base, MRI scans of arthralgia patients have not been studied. This is important as MRI is increasingly being used in the early recognition of RA. Moreover, inflammation in arthralgia patients is more subtle than in established RA and diagnostic properties can vary between populations with different prevalences of inflammation. Finally, tenosynovitis, which seems to be the most predictive MRI-detected feature (3, 4), has not been compared in the previous literature.

This study therefore aims to determine whether there is a difference between 1.5 T and 3.0 T MRI in the assessment of all relevant MRI features (synovitis, tenosynovitis, osteitis, and erosions) in arthralgia patients. This study does not address either 1.5 T or 3.0 T as the gold standard. Instead, we aspire to increase the feasibility of the use of MRI in arthralgia patients in general, by examining whether 3.0 T can be used if 1.5 T MRI is not available.

Method

Patient population

Between August 2019 and March 2020, participants in the TREAT EARLIER trial were asked to also participate in this comparative MRI study. The TREAT EARLIER is a randomized placebo-controlled proof-of-concept trial that evaluates the efficacy of a single dose of intramuscular corticosteroids and a 1 year course of methotrexate in preventing the development of clinical arthritis and RA. At trial inclusion, patients had arthralgia that was clinically suspect for progression to RA and subclinical inflammation in metacarpophalangeal (MCP) 2–5, wrist, and/or metatarsophalangeal (MTP) 1–5 joints MCP on contrast-enhanced 1.5 T MRI. During the trial follow-up period of 2 years, MRI scans were repeated at different time-points (4, 12, and 24 months). The trial is still ongoing and has been described in detail previously (13). In this study, 28 trial participants underwent a contrast-enhanced 3.0 T MRI along with one of the 1.5 T MRI scans that were performed as part of the trial follow-up (at 4, 12, or 24 months), permitting comparison between the two field strengths. Both scans were performed with at least 2 days in between them to allow for sufficient clearance of intravenous contrast, and within 7 days to prevent incomparability due to biological variation.

Ethics and consent

This study was carried out in compliance with the Declaration of Helsinki and all participating patients provided written informed consent. The study was approved by the medical ethical committee of the Leiden University Medical Centre (LUMC) (B19.008).

MRI protocol

Unilateral MRI scans were taken of the wrist, second to fifth MCP and first to fifth MTP joints of the most painful side, or the dominant side in the case of symmetrical symptoms. Patients were asked not to use any non-steroidal anti-inflammatory drugs (NSAIDs) during the 24 h before MRI.

The 1.5 T MRI was performed on an MSK Extreme extremity MRI system (GE, Wisconsin, USA), using a 100 mm coil. Patients were positioned in a chair beside the scanner, with the hand fixed in the coil with cushions.

The 3.0 T MRI was performed on a full-body MRI system (Philips, Best, Netherlands), using dedicated extremity coils for the hand and foot. Patients were positioned feet-first in the scanner, with the hand and foot fixed in the coil with cushions.

The sequences that were obtained after gadolinium–chelate enhancement (Dotarem, dose of 0.1 mmol/kg) on the 1.5 T were: T1 fast spin echo with selective fat saturation of MCP, wrist, and MTP region in the coronal and axial plane. On the 3.0 T, these sequences were: T1-weighted spectral adiabatic inversion recovery (SPAIR) of MCP, wrist, and MTP region in the coronal and axial plane. The field of view (FOV) was 140 mm for the forefoot on both field strengths. The FOV in the MCP region and wrist was 150 mm on 3.0 T and 100 mm on 1.5 T.

Further details on the MRI protocols are provided in the supplementary methods.

Image analysis

Each MRI scan was independently scored by two readers, blinded to clinical data. Field strengths were also scored independently. Both readers were PhD students and had at least 2 years of prior experience in scoring RAMRIS inflammation. Intraclass correlation coefficients (ICCs) on a 1.5 T test set before the start of this study were: 0.98 (intrareader 1), 0.94 (intrareader 2), and 0.96 (reader 1 vs reader 2). Erosions, osteitis, and synovitis were scored according to the RAMRIS method (2) and tenosynovitis according to Haavardsholm et al (14). Features were considered present if

scored as ≥ 1 by both readers. Features were summed into inflammation (osteitis, synovitis, and tenosynovitis) and RAMRIS (inflammation and erosions).

Further details on image analysis are provided in the supplementary methods.

Statistical analysis

ICCs (two-way mixed-effects model) of continuous scores were used to assess interreader reliability (comparing reader 1 and reader 2) and field strength agreement (comparing 1.5 T and 3.0 T).

ICC values were interpreted as follows: < 0.50, poor reliability; 0.50–0.7,5 moderate; 0.75–0.90, good; and > 0.90, excellent (15). Bland–Altman and correlation plots were drawn. Next, field strength agreement was determined after dichotomization of inflammation (present/absent) and calculated as the proportion of concordant scores. Analyses were performed on the patient and location levels (joint, bone, tendon sheath). SPSS version 25 (IBM Corp., Armonk, NY, USA) was used for analysis.

Results

Characteristics of the 28 included patients are given in supplemental Table 1. The mean age was 52 years (sd 14), 71% were female, and 21% were anti-citrullinated protein antibody (ACPA) positive. Median inflammation and RAMRIS scores were 3 and 5 on 1.5 T, respectively (Table 1). The mean scanning interval was 4 days. The scan times, without positioning and survey scans, were 25 min on 1.5 T and 20 min on 3.0 T. We kept an extended report of any adverse events, as these patients also participated in a randomized controlled trial (13). No side effects of any MRI, either 1.5 T or 3.0 T, were reported.

Interreader reliability

Interreader reliability on both 1.5 T and 3.0 T was excellent for RAMRIS and inflammation scores (ICCs ≥ 0.95) and good to excellent for separate features (ICC ≥ 0.82) (supplemental Table 2).

Field strength agreement: continuous scores

Median scores on both field strengths were similar (Table 1). Field strength ICCs were excellent for inflammation [0.90; 95% confidence interval (CI) 0.78–0.95] and RAMRIS (0.90, 95% CI 0.78–0.95). ICCs per feature were good to excellent for erosions, osteitis, and tenosynovitis (0.81, 95% CI 0.63–0.91; 0.96, 0.91–0.98; and 0.87, 0.74–0.97, respectively) and moderate for synovitis (0.65, 95% CI 0.24–0.84).

Bland–Altman and correlation plots showed that systematic bias was low and mainly caused by higher synovitis scores on the 3.0 T scan (Figure 1).

Field strength agreement: dichotomized scores

Agreement between dichotomized 1.5 T and 3.0 T scores was 89% for RAMRIS and 83% for inflammation (Table 2). Evaluating the RAMRIS features separately, less agreement was found for synovitis (68%) compared to the other inflammatory features (≥ 82%). Discordance was primarily caused by positive scores on 3.0 T with accompanying negative scores on 1.5 T.

On the location level, agreement was 98% and 97% for inflammation and RAMRIS scores, respectively. For synovitis, the agreement was 88% and for the other features > 96%.

For illustrative purposes, 1.5 T and 3.0 T MRI images of the same patient are presented in Figure 2.

Table 1. Agreement of different field strengths, scored according to the Rheumatoid Arthritis Magnetic Resonance Imaging Scoring system (RAMRIS), in arthralgia patients.

	Median score (IQR; max)		ICC (95% CI) 3.0 T–1.5 T		
	1.5 T	3.0 T	Reader 1	Reader 2	Mean of the two readers
RAMRIS	5 (2–8; 35)	7 (4–9; 31)	0.81 (0.62–0.91)	0.92 (0.82–0.96)	0.90 (0.78–0.95)
Inflammation	3 (2–4; 29)	4 (3–6; 25)	0.79 (0.60–0.90)	0.93 (0.83–0.97)	0.90 (0.78–0.95)
Erosions	2 (1–4; 7)	3 (2–4; 8)	0.78 (0.56–0.89)	0.77 (0.56–0.89)	0.81 (0.63–0.91)
Osteitis	1 (0–2;11)	1 (0–1; 11)	0.81 (0.63–0.91)	0.89 (0.71–0.95)	0.96 (0.91–0.98)
Synovitis	1 (0–3; 10)	3 (1–4; 8)	0.59 (0.26–0.79)	0.76 (0.28–0.90)	0.65 (0.24–0.84)
Tenosynovitis	0 (0–1; 8)	0 (0–1; 7)	0.66 (0.39–0.82)	0.81 (0.63–0.91)	0.87 (0.74–0.94)

Medians of the mean score of the two readers are given in the first column. Intraclass correlation coefficients (ICCs) are based on single measure in a two-way mixed-effect model. RAMRIS is the summed score on erosions, osteitis, synovitis, and tenosynovitis. Inflammation is the summed score on osteitis, synovitis, and tenosynovitis.
IQR, interquartile range; max, maximum; CI, confidence interval.

Table 2. Agreement of the two field strengths on dichotomized scores on (A) the patient level and (B) the location level.

	Concordance			Discordance	
	1.5 T+/3.0 T+	1.5 T–/3.0 T–	Agreement	1.5 T–/3.0 T+	1.5 T+/3.0 T–
(A) Patient level					
RAMRIS (%)	89	0	89	11	0
Inflammation (%)	79	4	83	18	0
Erosions (%)	75	11	86	14	0
Osteitis (%)	43	39	82	11	7
Synovitis (%)	57	11	68	32	0
Tenosynovitis (%)	32	57	89	7	4
(B) Location level					
RAMRIS (%)	3	94	97	2	1
Inflammation (%)	2	96	98	2	1
Erosion s(%)	5	91	96	2	2
Osteitis (%)	1	97	98	1	1
Synovitis (%)	5	83	88	9	3
Tenosynovitis (%)	1	97	98	1	1

+, Presence of a feature or summed score ≥ 1; –, absence of a feature or summed score < 1.
Field strength agreement was determined after dichotomization into the presence or absence of inflammation and calculated as the proportion of concordant dichotomized scores on both field strengths. A feature or summed score was considered present if scored ≥ 1 by two readers. RAMRIS is the summed score on erosions, osteitis, synovitis, and tenosynovitis. Inflammation is the summed score on osteitis, synovitis, and tenosynovitis. Results are given as the percentage of the total number of patients (n = 28): (A) bones, joints, and tendon sheaths (n = 2968); (B) 924 bones are scored for erosions and osteitis (224 in hands, 420 in wrists, and 280 in feet), 336 synovial linings are scored for synovitis (112 in hands, 84 in wrists, and 140 in feet), and 784 tendons are scored for tenosynovitis (224 in hands, 280 in wrists, and 280 in feet).

Discussion

Predictive values of MRI in RA and pre-RA have been mostly acquired on 1.0–1.5 T. However, 3.0 T is now being increasingly used in the early recognition of RA. Scientific evidence on the comparability of assessment of subclinical inflammation with these field strengths is scarce, and is unavailable in arthralgia patients without clinical arthritis. We showed that agreement between 1.5 T and 3.0 T was predominantly good to excellent, but moderate for synovitis. Our research suggests that scientific results on the predictive value of subclinical inflammation and tenosynovitis, obtained on dedicated extremity 1.5 T, can be generalized to large-bore 3.0 T when used in daily practice. However, when assessing synovitis as a separate feature on 3.0 T, it should be kept in mind that synovitis scores on this field strength could be somewhat increased compared to 1.5 T.

The 3.0 T was slightly more sensitive for synovitis, leading to moderate agreement for this feature on a patient level. The most important explanation for this minor difference is the dependence on field strength of tissue contrast enhancement and the ensuing contrast between enhancing and non-enhancing tissue. The higher the field strength, the higher the signal intensity on gadolinium–chelate-enhanced T1-weighted images (16, 17). Reassuringly, on a location level, dichotomized agreement on synovitis was high. Moreover, for tenosynovitis, inflammation, and RAMRIS, agreement was excellent. From the different inflammatory features, tenosynovitis and inflammation have been shown to be considerably more predictive for the development of clinical detectable arthritis, and osteitis is the inflammatory feature that is most predictive for erosion development (1, 18, 19). In contrast, synovitis is not an independent predictor and subtle synovitis (grade 1) is common in older healthy individuals (1, 18, 20). Furthermore, the different inflammatory features often occur concomitantly in patients. Altogether, although the agreement for synovitis was moderate compared to 1.5 T and we have no gold standard, the reliability between 3.0 and 1.5 T of most features was very high. We therefore assume that the predictive accuracy of MRI on 3.0 T on a patient level is not considerably different compared to 1.5 T MRI.

Future longitudinal research should determine whether any added predictive value exists for the 3.0 T MRI as a more sensitive modality for the detection of synovitis. Furthermore, the benefit of automatic or semi-automatic artificial intelligence-based segmentation methods could be investigated on both field strengths. In addition, a potential advantage of large-bore 3.0 T is the larger field of view compared

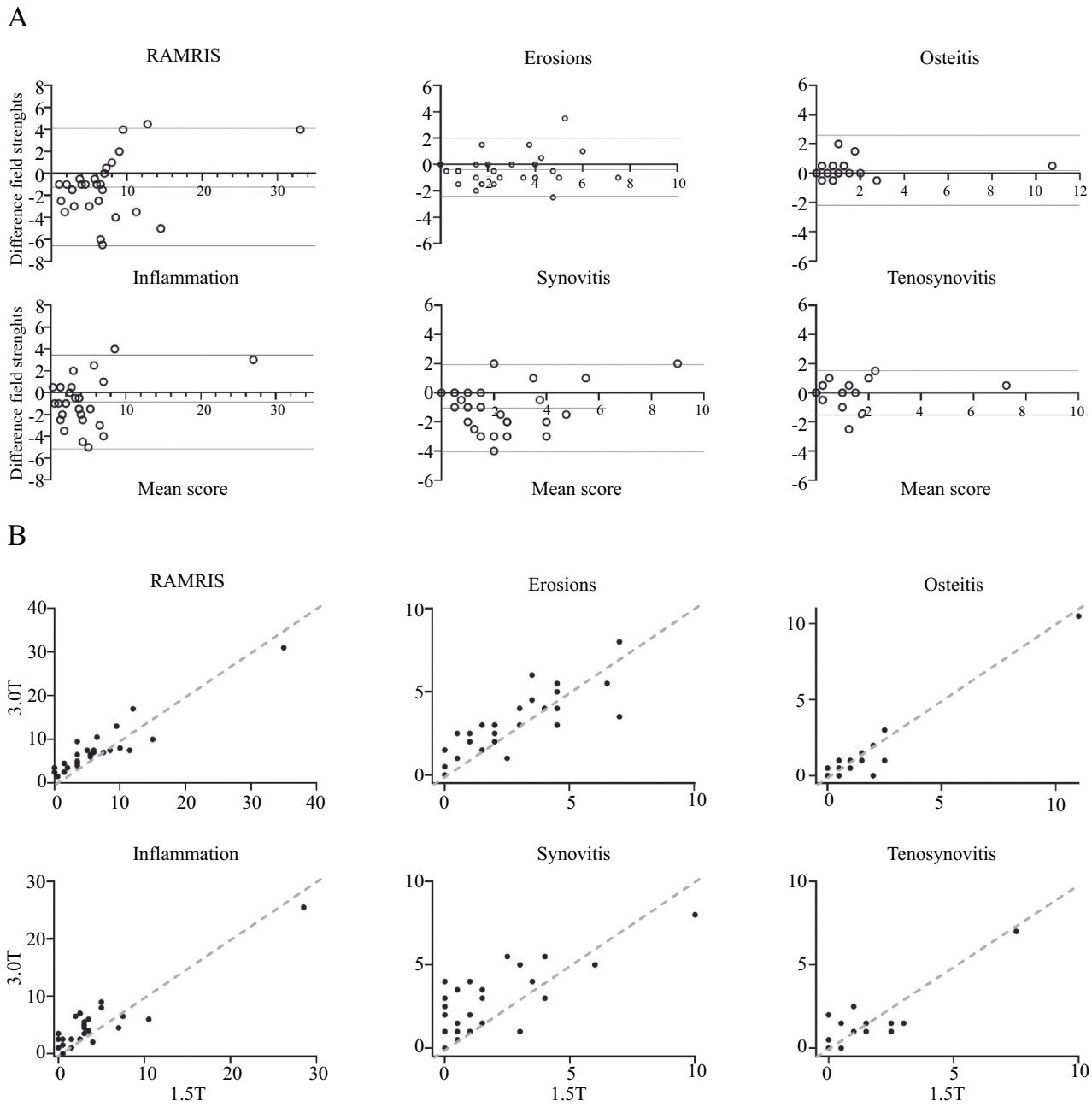

Figure 1. (A) Bland–Altman plots and (B) correlation plots comparing 1.5 T and 3.0 T magnetic resonance imaging. (A) Bland–Altman plots depicting agreement between two field strengths for summed inflammation and Rheumatoid Arthritis Magnetic Resonance Imaging Scoring system (RAMRIS) scores and for each feature separately. The y-axes demonstrate the absolute difference between 1.5 T and 3.0 T. The x-axes denote the average score of two field strengths [(1.5 T + 3.0 T)/2]. The middle grey line depicts the mean difference between the field strengths, and the upper and lower lines depict the ± 95% limits of agreement. (B) Pearson's correlation coefficients on log-transformed scores are 0.86 ($p < 0.01$) for RAMRIS score, 0.75 ($p < 0.01$) for inflammation score, 0.85 ($p < 0.01$) for erosions, 0.86 ($p < 0.01$) for osteitis, 0.60 ($p < 0.01$) for synovitis, and 0.77 ($p < 0.01$) for tenosynovitis. The middles dotted reference line depicts absolute agreement between the two systems. RAMRIS is the summed score on erosions, osteitis, synovitis, and tenosynovitis. Inflammation is the summed score on osteitis, synovitis, and tenosynovitis.

to 1.5 T extremity MRI, allowing a reduction in MRI scan time. This potential advantage could be further explored.

The current study is the first study comparing field strengths in arthralgia patients, which is a meaningful advance, as MRI plays a prominent role in risk prediction in this early stage of the disease. Only one small study has compared MRI-detected RAMRIS features on contrast-enhanced 1.5 T and 3.0 T in established RA patients (12). This previous study is concordant in their finding that no significant differences on the number and extent of erosions, osteitis, and synovitis exist between 1.5 T and 3.0 T. In addition, our data suggest that tenosynovitis is also reliably assessed on both field

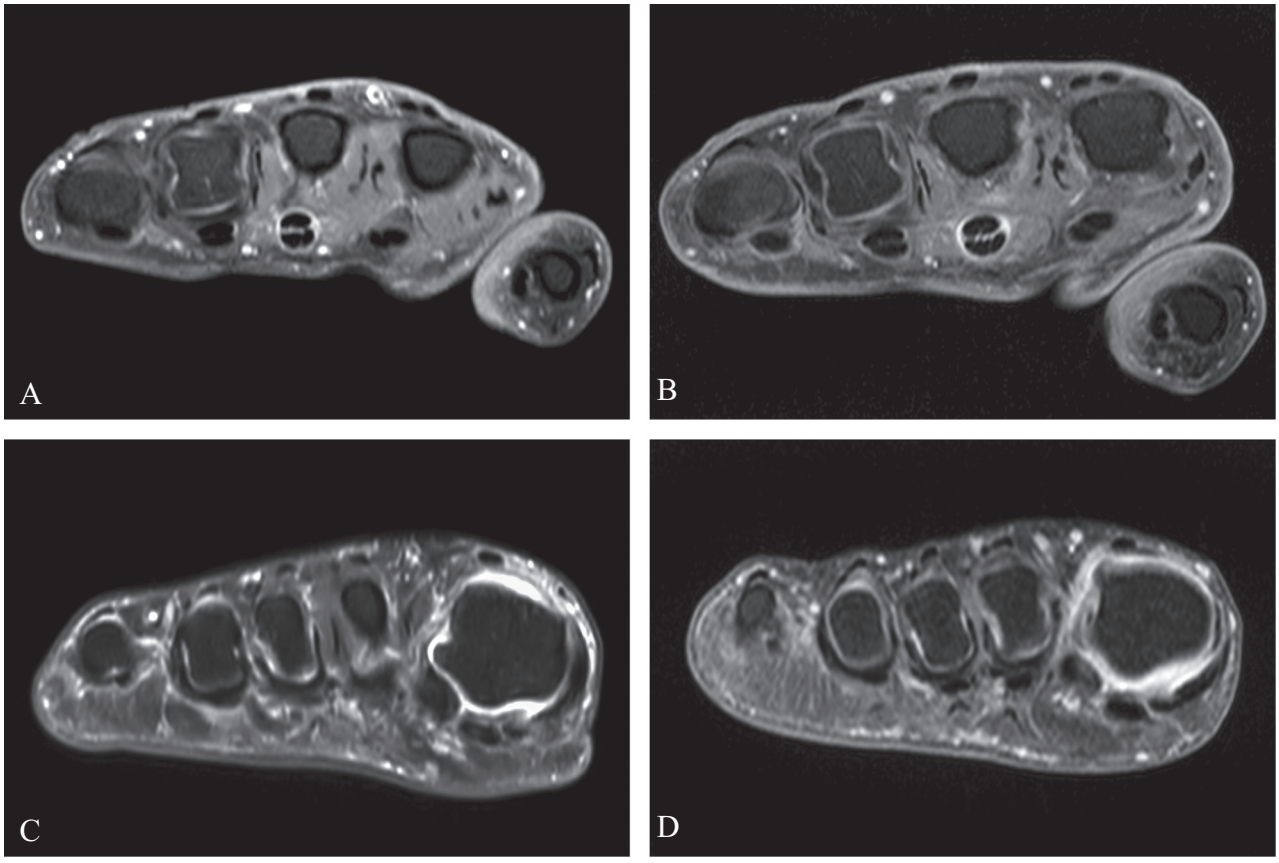

Figure 2. Examples of a contrast-enhanced magnetic resonance imaging (MRI) sequence of the metacarpophalangeal (MCP) region with tenosynovitis and metatarsophalangeal (MTP) region with synovitis in the same patient, scanned at 3 T and 1.5 T. (A, B) Tenosynovitis of the third flexor tendon sheath in the MCP region on 3.0 T (A) and 1.5 T (B) MRI. (C, D) Synovitis of the first MTP joint on 3.0 T (C) and 1.5 T (D) MRI.

strengths. This is important in the phase of arthralgia, as tenosynovitis has the highest predictive value for RA development (3, 4).

This study has some limitations that should be acknowledged. First, since the study was performed in arthralgia patients, it important to consider that the current results cannot be directly extrapolated to other populations, such as established RA patients. The choice to study arthralgia patients could have posed a statistical hurdle in assessing agreement measures, since ICCs are sensitive to a lack of variability among sampled subjects and subclinical inflammation is, by definition, reflected by low RAMRIS scores with low variability (15). Nevertheless, reliability and agreement scores of RAMRIS features were largely good to excellent.

Secondly, another possible limitation in this study is that readers only had previous experience with scoring 1.5 T images and not with 3.0 T images. Reassuringly, however, interreader ICCs were good to excellent on both MRI scans.

Thirdly, arthralgia patients in this study may have been treated with methotrexate in the context of the TREAT EARLIER trial. This possibly influenced the amount and presence of subclinical MRI inflammation in these patients. However, as this study has a cross-sectional design, this could not have influenced the comparison between field strengths.

Finally, a limitation could be that we applied the scoring method developed by Haavardsholm et al for tenosynovitis (14). The RAMRIS was recently updated and now includes a slightly modified tenosynovitis score (21) However, as both field strengths were scored according to the same protocol in this study, comparability could be adequately assessed. Based on the current results, differences in agreement between 1.5 T and 3.0 T when using updated protocols are not expected.

A strength of this study is the scoring of all images by two independent readers, blinded to the results of the other field strength, thus ascertaining a reliable comparison between the two field strengths.

Conclusion

Although the moderate agreement on synovitis between the two field strengths should be taken into account, the current data imply that scientific results on the predictive value of MRI-detected inflammation, obtained on 1.5 T MRI, may be generalized to 3.0 T MRI when used in daily practice.

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Author contributions

DK, JLB, MR, and AHMvdHvM were involved in study conception and design. MV, FW, and DK contributed to collection of the data. DK performed the data analyses. DK and AHMvdHvM evaluated and interpreted the results. DK and AHMvdHvM wrote the first version of the manuscript and JLB and MR critically revised it. All authors read and approved the final manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability statement

Data are available from DK upon reasonable request.

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Supplementary material

Supplemental data for this article can be accessed here.