Quantitative, small bore, 1 Tesla, magnetic resonance imaging of the hands of patients with rheumatoid arthritis

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Abstract

Objective

To determine if quantitative hand images obtained from an office-based MRI extremity scanner reliably distinguish patients with rheumatoid arthritis from controls.

Methods

The hands of 39 patients suffering from rheumatoid arthritis were imaged using a small bore, 1.0 Tesla Magnetic Resonance Imager. Non-contrast images of the metacarpophalangeal joints and wrist joints were evaluated using a method based on the validated rheumatoid arthritis magnetic resonance imaging system (RAMRIS). The extent and degree of synovitis, bone edema and bone erosions was assessed. Derived scores were compared with the corresponding scores for groups of younger (n=14) and older (n=27) controls with no signs or symptoms of joint disease.

Results

The mean (± standard error) total joint scores were 0.3±0.2 for young controls, 11.5±2.4 for older controls and 34.1±6.0 for the patients with rheumatoid arthritis. The greatest difference between rheumatoid patients and older controls was observed for synovitis with scores that were greater by a factor of almost 6.5. Scores for erosions and edema were factors of 2.9 and 2.3 greater in rheumatoid arthritis than in controls. The relationship between scores for the same joints on the dominant and non-dominant sides was generally stronger than the relationship between the metacarpophalangeal and wrist joints of the same hand.

Conclusion

These observations indicate that scoring of hand images obtained from a small bore, office based, 1.0 Tesla MR imager have clinical validity and may be used to distinguish patients with rheumatoid arthritis from aged matched controls.

Key words

Magnetic resonance imaging, rheumatoid arthritis, hand imaging.

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Conflict of interest:
Dr. J.D. Adachi is a consultant/speaker for Amgen, Astra Zeneca, Eli Lilly, GSK, Merck, Novartis, Pfizer, Proctor & Gamble, Roche, Sanofi Aventis, Servier and Wyeth, and gas conducted clinical trials for Amgen, Eli Lilly, GSK, Merck, Novartis, Pfizer, Proctor & Gamble, Roche, Sanofi Aventis and Wyeth; the other co-authors have declared no competing interests.

Introduction

Musculoskeletal diseases are the major cause of morbidity throughout the world, inflicting enormous cost burdens on health care systems in addition to negatively impacting health and quality of life. The cost of such diseases in the United States now approaches about 3% of GDP which is equivalent to a mild recession (1). In Canada, musculoskeletal diseases are the second most expensive category behind cardiovascular disease and ahead of cancer (2). The two most common musculoskeletal diseases are rheumatoid arthritis and osteoarthritis; the prevalence of the former in the US is 2,601 per 10^5 women aged 60-69, about double the prevalence in men (1).

Rheumatoid arthritis is diagnosed clinically through the assessment of pain, swelling and stiffness in the joints of the hand combined with radiographic evidence gleaned from conventional hand radiographs. The clinical symptoms are a consequence of the inflammatory process underway in joints and any detectable radiographic evidence originates from cellular responses to the disease process. It may be possible to identify rheumatoid arthritis at an earlier stage than is possible from radiographs if the basis of detection shifts from assessment of disease outcome in hard tissues to the identification of the early stages of inflammation in the soft tissues and the subchondral bone of affected joints. The obvious imaging modality to satisfy such a role is magnetic resonance (MR) imaging. However, access to hospital based, whole body MR systems is sometimes limited and patients may encounter long wait times. In addition, 1.5 Tesla (T) and 3.0T whole body instruments have high capital and operating costs. Small bore, office based MRI devices have considerable advantages in terms of costs, patient comfort and facility requirements (3, 4). In addition, comparisons between conventional high field 1.5T MRI machines and low field 0.2T dedicated extremity MRI devices show similar diagnostic accuracy, specificity and sensitivity for patients with rheumatoid arthritis (5, 6). The purpose of this paper is to present the results of an evaluation of quantitative hand imaging in patients with and without rheumatoid arthritis using an office based, small bore, medium field 1.0T peripheral MR imager that is dedicated to rheumatological applications.

Materials and methods

Patient and volunteers

A total of 80 subjects were recruited and were allocated to one of three groups. Thirty-nine patients (31 female, 8 male) suffering from rheumatoid arthritis (RA) were recruited through two rheumatology clinics. The patients ranged in age from 26 to 83 years (mean±SD: 54±15) although only two were younger than 35. The duration of RA was from 2 months to 15 years with an average of 5.5 years.

Two control groups were assembled from members of the local community. An older control group included 27 subjects (22 female, 5 male) with ages ranging from 49 to 74. The mean age for the older controls was 62±7 years. The second control group consisted of 14 subjects (4 female, 10 male) with ages ranging from 19 to 33. The mean age for the younger controls was 25±5 years. No control subject had any evidence of joint disease when evaluated by a rheumatologist.

Each subject underwent metacarpophalangeal (MCP) and wrist joint MR imaging. Thirty-five of 39 patients in the RA group had both right and left hands imaged. The remaining 4 had only the dominant side MCP and wrist joints imaged. In the older control group, 24 of 27 had bilateral imaging while all 14 patients in the young control group had both hands imaged.

The statistical significance of differences between groups was assessed using *t*-tests and $p<0.05$ was selected as the level of significance. The study was approved by the Research Ethics Board of McMaster University and Hamilton Health Sciences.

MR imaging

MR scans were performed using an ONI Medical Systems OrthOne 1.0T peripheral scanner with a 123 mm removable quadrature volume transmit-receive coil. The selected imaging

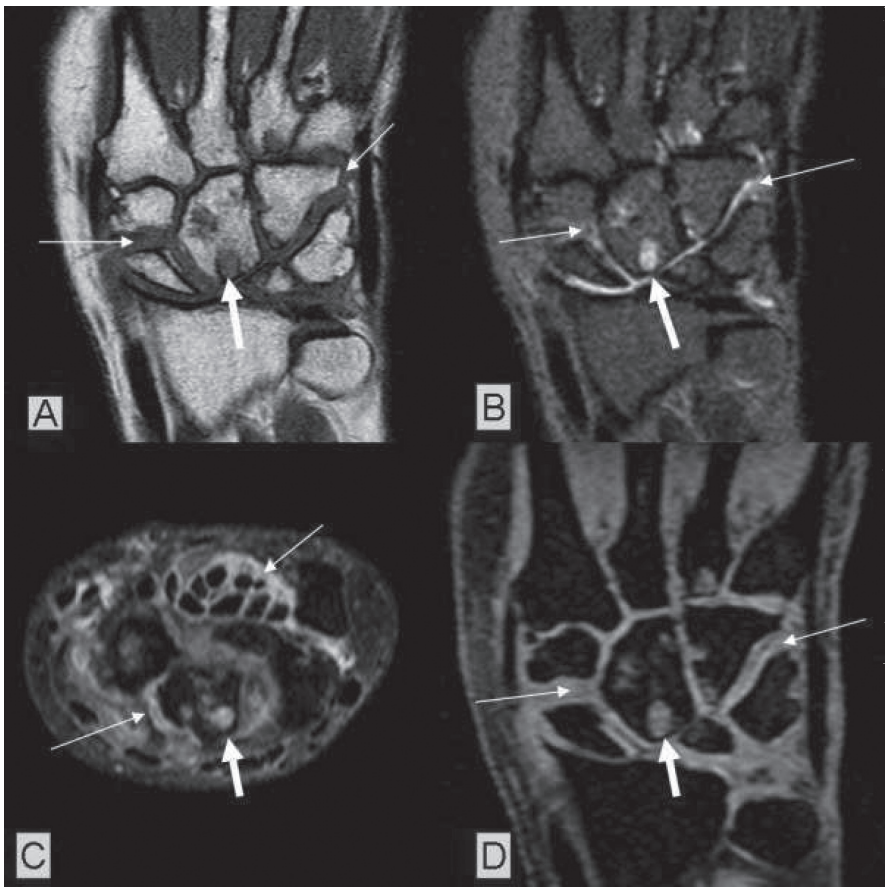

Fig. 1. Example hand images from the 1Tesla OrthOne: (**A**) FSE T1 weighted coronal image; (**B**) FSE inversion recovery coronal image; (**C**) FSE T2 weighted axial scan; (**D**) 3D gradient echo fat saturated coronal image.

Table I. Sequence specification for the MRI scans.

Feature	FSE T1	FSE IR	FSE T2 Fat. Sat.	3DGE Fat. Sat.
Orientation	Coronal	Coronal	Axial	Coronal
Number of Slices	18	18	21	26
Gap (mm)	0	0	0	0
Thickness (mm)	2	2	2	1
Range (mm)	36	36	42	26
Frequency	384	256	256	256
Phase	256	192	160	128
FOV (mm)	110	110	110	110
Excitation	1	1	2	1
TR (msec)	1000	4100	2570	70
TE (msec)	min	min	40	min
T1 (msec)	NA	90	NA	NA
Duration	2:12	1:42	3:31	3:54
Freq. Direction	H/F	H/F	L/R	H/F
Flip Angle	NA	NA	NA	30
Minimum TE	Yes	Yes	Yes	×
Inversion Recovery	×	×	Yes	×
Fat Suppression	Yes	×	×	Yes
Graphic SL	Yes	Yes	Yes	Yes

protocol consisted of one positioning scan and 4 diagnostic sequences. To ensure the joint of interest is completely located in the field of view, a 13-second scan consisting of a fast spin echo (FSE), axial T1 sequence with 4mm slice thickness is performed. Example diagnostic images from one subject are presented in Figure 1. The first diagnostic sequence is a FSE, T1-weighted, coronal scan with 18 contiguous slices (Fig. 1A). The acquisition parameters are given in Table I. The objective of the first sequence is to image synovial joint anatomy and to identify erosive bone lesions and swollen soft tissue. The second and third scans are, respectively, a FSE inversion recovery, coronal scan (Fig. 1B) followed by a FSE, T2-weighted, axial scan with fat saturation (Fig. 1C). These two sequences are sensitive to bone edema, synovitis and cystic bone erosions because of the free water content. The coronal and axial planar scans provide a comprehensive coverage of the region of interest. The final sequence is a three dimensional (3D) gradient echo, T1-weighted, coronal image with fat saturation (Fig. 1D). This sequence has the highest spatial resolution with the lowest slice thickness and provides the opportunity for 3D image segmentation and subsequent numerical quantification of tissue morphometry. It is anticipated that such segmentation will ultimately allow volume evaluation of cartilage and bone erosions when the appropriate software has been developed and validated. The parameters for the additional three sequences are also given in Table I. The complete protocol requires 11 minutes and 30 seconds of scanning time. Such a scanning time represents a compromise between extending data acquisition to improve image quality and minimizing scan time to help subjects, particularly the elderly, remain stationary for the entire scanning duration so as to minimize the potential for motion artifacts.

A second series of diagnostic images illustrating the appearance of bone edema is shown in Figure 2. The FSE T1 weighted coronal image (Fig. 2A) shows clearly one region of bone edema in the lunar bone and one less evident region in the scapular. The FSE inversion recovery sequence (Fig. 2B) shows both regions clearly. Edema is also evident on the FSE T2 weighted axial image (Fig. 2C).

Evaluation of MR images

Hand MR images were evaluated using a modified version of the OMERACT

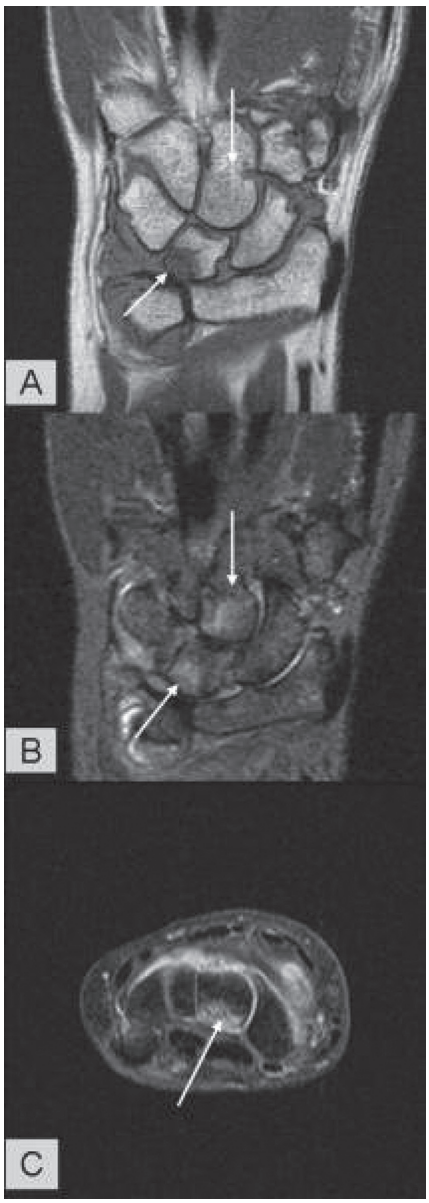

Fig. 2. Additional example images illustrating the appearance of bone edema: (**A**) obvious edema in the lunar but less evident edema in the scapular on the FSE T1 weighted coronal image; (**B**) edema present in each bone on the FSE inversion recovery coronal image; (**C**) edema also present on the FSE T2 weighted axial scan.

RAMRIS (Outcomes of Rheumatoid Arthritis Clinical Trails; rheumatoid arthritis magnetic resonance imaging system) scoring system (7). The original RAMRIS was based on MR imaging using whole body 1.5T imagers and evaluated the 3 main features of RA: synovitis, bone marrow edema and bone erosion. Synovitis was to be evaluated from gadolinium enhanced images. For office based, small bore MR systems, contrast enhancement may not be a practical option because it is invasive, expensive and carries a small but finite risk of anaphylactic reaction (8). Thus, we substituted the T2-weighted sequence with fat saturation for the assessment of synovial changes.

Synovitis is graded on a scale of 0 to 3 at each MCP joint (from 2nd to 5th). A grade of 0 corresponds to a normal appearance while grades 1, 2 and 3 correspond to the extent of the synovitis involvement (<33%; 34-66%; >67%). The maximum score for MCP synovitis is 12. For the wrist, 3 sites are examined: the radioulnar, radiocarpal and the intercarpal-carpometacorpal joints with the maximum score being 9.

Bone edema is also graded on a scale of 0 to 3 according to the proportion of bone involved. A one cm length of bone extending either proximally or distally from the articular surface at the MCP joint is assessed separately, yielding 8 sites for evaluation and a maximum edema score of 24. For the wrist, 15 sites are evaluated for edema. These sites are the bases of the first to the fifth metacarpals, the 8 carpal bones and the distal radius and ulna. The maximum wrist score for edema is 45.

Bone erosion is scored on a scale of 1 to 10 according to the extent of bone that has been eroded. Each incremental increase on the bone erosion scale corresponds to the removal of an additional 10% of the area of the bone examined. Again, 1 cm lengths of bone extending proximally and distally from the MCP joint are assessed, yielding 8 sites for evaluation and a maximum score of 80. For the wrist, the same 15 sites that are examined for edema are assessed for erosions so that the maximum erosion score at the wrist is 150.

Reproducibility of the scoring system was assessed when 2 readers repeated evaluations for 5 patient studies after an interval of 1 week. For each patient, 4 MCP and 1 wrist joint were assessed together with the following bone sites: 4 proximal phalanges; 4 metacarpal heads; 5 metacarpal bases; 8 carpal bones, the radius and the ulna. Both readers are experienced musculoskeletal radiologists. The more experienced reader of hand MRI images (XX) trained the second reader (HW) by evaluating images from 2 representative patients. The second reader was observed as a further 5 cases were scored and questions were addressed and assigned consensus scores. Each reader then scored 5 new cases which had had all patient information removed. One week later the 5 cases were re-scored.

Results

There was a close correspondence between the first and second scores when the MR images for 5 patients were evaluated on 2 occasions separated by 1 week. The correlation coefficient for the 2 sets of scores assigned by the first reader was 0.994 for the MCP joints and 0.997 for the wrist joints. For the second reader, the correlation coefficients were 0.977 for the MCP joints and 0.990 for the wrist.

In the young control group almost all MCP and wrist joints were healthy. Only in two cases was mild edema (grade 1) observed in the dominant metacarpophalangeal (DM) joints. Again, two cases of mild edema were observed in the non-dominant metacarpophalangeal joints (NDM). There was no synovitis or bone erosion seen in young controls.

For the 27 subjects who comprised the older control group, there were a few cases of synovitis and bone edema and many examples of bone erosion. Synovitis was observed in 4 DM joints; bone edema was found in 3 while bone erosions were seen in 12. Synovitis was observed in 1 dominant wrist (DW) joint; bone edema was found in 9 wrists while bone erosions were seen in 24. Twenty-four of the 27 older controls had the non-dominant hand imaged. For the NDM joints, synovitis was observed in 1 subject; bone edema in 5 and bone erosions were seen in 8. For the non-dominant wrist (NDW) joints, synovitis was observed in 2 older controls; bone edema was seen in 10 while bone erosions were identified in 21. The mean scores for synovitis, bone edema and bone erosions in the older controls are presented in Table II.

Not one of the 39 RA patients had a total score of zero although one had only a small bone erosion in the dominant wrist. Eighteen had synovitis in the

Table II. Comparison of scores (mean±SEM) for synovitis, edema and erosions identified at the dominant metacarpophalangeal (DM), the non-dominant metacarpophalangeal (NDM), the dominant wrist (DW) and the non-dominant wrist (NDW) joints.

	Young control	Older control	Rheumatoid arthritis
DM synovitis	0	0.29 ± 0.15	1.35 ± 0.39
DM edema	0.14 ± 0.10	0.29 ± 0.20	0.53 ± 0.22
DM erosion	0	1.51 ± 0.44	4.61 ± 1.03
NDM synovitis	0	0.04 ± 0.04	0.74 ± 0.22
NDM edema	0.14 ± 0.10	0.33 ± 0.16	0.14 ± 0.09
NDM erosion	0	0.91 ± 0.35	2.91 ± 0.58
DW synovitis	0	0.03 ± 0.04	1.05 ± 0.38
DW edema	0	0.85 ± 0.27	1.97 ± 0.46
DW erosion	0	3.11 ± 0.47	7.79 ± 1.39
NDW synovitis	0	0.16 ± 0.13	0.85 ± 0.37
NDW edema	0	1.00 ± 0.32	2.85 ± 0.95
NDW erosion	0	3.20 ± 0.70	9.97 ± 2.22

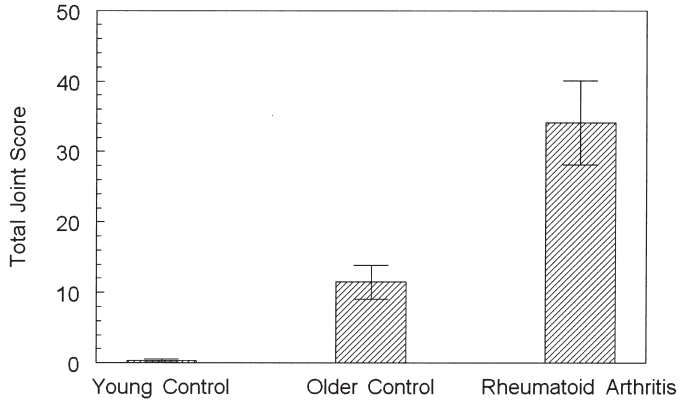

Fig. 3. Total joint score (mean±standard error of the mean) for both hands in 35 patients with rheumatoid arthritis, 24 older controls and 14 young controls.

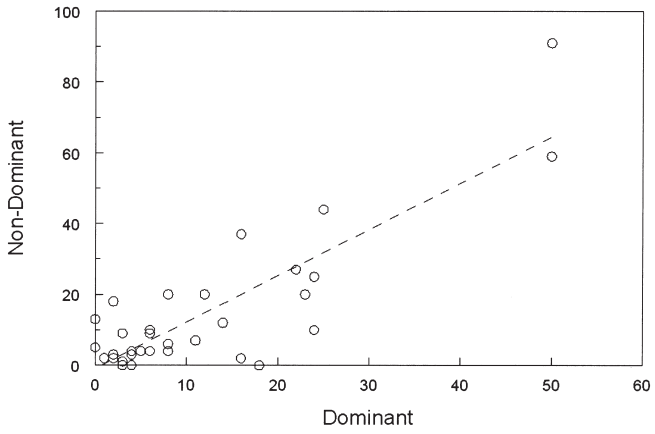

Fig. 4. Relationship between joint score for the dominant and non-dominant wrists in patients with rheumatoid arthritis.

DM joints; 11 had bone edema and 31 had bone erosions. In the DW, 11 patients had synovitis; 23 had bone edema and 38 had bone erosion. For the non-dominant joints only 35 subjects were involved. Synovitis was detected in 14 NDM joints; bone edema was present in 3 and bone erosions were present in 26 of 35. For the NDW, synovitis was seen in 10 out of 35; bone edema was detected in 19 and bone erosions were observed in 29. The mean scores for the RA patients are also listed in Table II.

A total joint score can be derived as the sum of the scores for synovitis, edema and bone erosions at the dominant and non-dominant MCP and wrist joints. Fig. 3 compares the total joint scores for those subjects from the three groups who had both hands imaged. There is a statistically significant difference between the older controls and the patients with rheumatoid arthritis ($p<0.005$). The relatively large standard deviation for the older controls prevents the difference between the two control groups from achieving statistical significance ($0.4>p>0.2$).

Fig. 4 shows the correlation between scores for the dominant and non-dominant wrist joints of the patients with rheumatoid arthritis. The correlation coefficient was 0.85. For the dominant and non-dominant MCP joints, the correlation coefficient was 0.61. These results show that the MR appearance of either the MCP or wrist joint of one hand bears a close relationship to the MR appearance of the corresponding contralateral joint. When the relationship between the MR scores of the MCP and wrist joints on the same side is examined, weaker correlations are observed. For the dominant side, the correlation coefficient between the MCP and wrist joint scores was 0.22 while for the non-dominant side, the coefficient was 0.62. This means, at least for the wrists, the MR expression of rheumatoid arthritis is more similar between the two wrists than it is between the MCP joints and the wrist joints of the same hand.

Discussion

With a small bore peripheral MR device, it is plausible to scan patients on the same day that an appointment is scheduled with a physician. A medium field strength (1.0T) peripheral scanner has the same advantages as a low field strength (0.2T) peripheral scanner with a superior image quality. As illustrated in Figures 1 and 2, the quality of hand images produced from a 1.0T small bore device appears, at least superficially, to be equivalent to that obtained from large bore, whole body instruments of greater field strength. Access to the large bore machines can never be as immediate as the small bore instruments because of the broad variety of examinations offered and because of the high demand for whole body MR imaging. A device restricted to appendicular examinations and located in the rheumatology clinic is more likely to meet the demands of same-day imaging.

The comparison of total joint scores between controls and patients with

rheumatoid arthritis show that the scoring system is sufficiently sensitive to discriminate between RA patients and controls. In addition, repeat analyses of MR studies show that the scoring system is reproducible provided sufficient time and effort is invested in training and reviewing the image evaluation criteria. The apparent difference between younger and older controls, which only approached statistical significance, originated principally from the presence of bone erosions in the elderly. The mean scores (±SEM) for bone erosions, edema and synovitis in the older controls were 8.5±1.7, 2.5±0.7 and 0.58±0.6 respectively. The corresponding scores for the younger controls were all equal to or close to zero. For completeness, the corresponding scores for the RA patients were 24.6±4.3, 5.7±1.4 and 3.8±1.0 respectively. It appears that the MRI score should be regarded as a gradient of risk for the presence and severity of RA over and above the expected joint changes due to age related degenerative disease.

The relatively dominant contribution of bone erosions to the total joint score arises principally from the weighting assigned during the development of the scoring system. The maximum total scores for erosions, edema and synovitis are 230 (80+150), 69 (24+45) and 21 (12+9), respectively. If scores are expressed as a percentage of the maximum possible score, the mean scores for erosions, edema and synovitis in older controls become 3.7, 3.6 and 2.8%. For the RA patients, the corresponding percentages are 10.7, 8.3 and 18.1%. When normalised in this fashion, the greatest difference between older controls and patients with rheumatoid arthritis is observed through assessment of synovitis.

In our study, synovitis was visible as a fluid signal distending the joint cavity. Synovial tissue could not be differentiated reliably from synovial fluid with the sequences used in this study. Discrimination between these two components of the synovial cavity typically requires the use of contrast. The injection of gadolinium would have increased the complexity, cost and duration of the examination. Moreover, diffusion of the contrast agent from the synovium into the adjacent joint fluid is known to occur rapidly in small joints and would obscure the synovium. Accordingly, we decided not to attempt to discriminate between the synovium and synovial fluid particularly because both were essentially features of the same process of synovitis (5, 10).

The correlation (r=0.85) shown in Figure 4 between joint scores for the dominant and non-dominant wrists of patients with RA is consistent with the known symmetrical nature of RA (9). The correlation (r=0.61) between the dominant and non-dominant MCP joints was not as strong. The correlation coefficient between the MCP and wrist joint scores was less strong on the dominant (r=0.22) and similar for the non-dominant side (r=0.62). In general, there was a greater similarity between corresponding joints than between joints on the same hand. This observation again supports the sensitivity of extremity MR imaging combined with quantitative image evaluation to the presence and extent of expression of RA symptoms in the hands.

Potential areas for strengthening the current scoring system include evaluation of cartilage thinning and assessment of the extent of focal cartilage damage. Clearly, Figure 1D demonstrates that cartilage can be visualized using a 1.0T extremity MR imager. The need will be the development of image processing software with the ability to extract indices of cartilage integrity from T1 weighted coronal images. Another possible feature detectable in 1.0T MR images which may contribute to the discrimination between patients with RA and controls, is the numerical grading of tendonitis and tenosynovitis and the recognition of features such as effusions and cortical irregularity. Currently, synovitis and joint effusion will appear the same in our evaluation system and it may be that these features can only be distinguished with the use of contrast. However, the extent of joint effusion correlates with synovial inflammatory activity (10) and consequently, contrast may not be essential. Further work is required to evaluate these potential enhancements to the hand RA scoring system. Nevertheless, these results have shown that the current system, as currently configured, distinguishes between older controls and patients with RA suggesting that it has clinical validity. The work reported here has shown that the presence of RA in the hands of patients can be observed using 1.0T extremity MR imaging without administration of contrast enhancement and that a reproducible assessment of the extent of involvement is possible using an OMERACT-RAMRIS based scoring system.

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