Magnetic Resonance Imaging Appearance of the Hands and Feet in Patients with Early Rheumatoid Arthritis

NATHALIE BOUTRY, ANNE LARDÉ, FRANCK LAPÈGUE, ELIZABETH SOLAU-GERVAIS, RENÉ-MARC FLIPO, and ANNE COTTEN

ABSTRACT. ***Objective.*** To describe the magnetic resonance (MRI) imaging findings of the feet in patients with early rheumatoid arthritis (RA), and to compare MRI appearance of the feet with that of the hands.

Methods. Thirty consecutive patients (18 women, 12 men; age range 19–64 yrs) with early RA underwent MRI of hands and feet. Axial fat suppressed gadolinium enhanced T1 weighted spin-echo and gadolinium enhanced 3-dimensional gradient-echo (FLASH) images were obtained.

Results. In the hands, MRI findings suggested active synovitis of the wrist and metacarpophalangeal (MCP) joints in 28 (93%) and 27 (90%) patients, respectively. In the feet, active synovitis was observed in 29 (97%) patients. Bone erosions were seen in the wrist joints in 24 (80%) patients. Observers found as many bony changes in the MCP as in the metatarsophalangeal joints [23 (77%) patients]. MRI detected tenosynovitis in 16 (53%) patients in the hands, and in 18 (60%) patients in the feet. Bursitis located between or beneath the metatarsal heads was a common MRI finding [19 (63%) patients].

Conclusion. Additional MRI of the feet may be useful when evaluation of the hands does not help identify early RA. (J Rheumatol 2003;30:671–9)

Key Indexing Terms:
RHEUMATOID ARTHRITIS MAGNETIC RESONANCE IMAGING HAND ARTHRITIS

Early detection of synovitis and bone erosions in rheumatoid arthritis (RA) is required to determine the best therapy and therefore to prevent progression of joint destruction and longterm disability. Magnetic resonance imaging (MRI) has been established as the most sensitive means for detection of active synovitis and bone erosions in early stage RA[1-5]. Many studies[1,3,5-7] have focused on the MRI appearances of the hands. In contrast, there are no relevant reports about the MRI characteristics of the feet in early RA. At the start, however, more foot joints are affected than hand joints[8]. In addition, radiographic changes in the feet can reportedly antedate those of the hands[9,10]. The purpose of our study was 2-fold: first, to describe the MRI features of metatarsophalangeal (MTP) joints in early RA, and second, to compare MRI appearance of the feet with that of the hands.

MATERIALS AND METHODS

Patients. From November 1999 through March 2001, 30 patients who secondarily fulfilled the 1987 American College of Rheumatology (ACR) criteria for the diagnosis of RA[11] underwent MRI of the hands and feet. The study protocol was approved by our institutional review board, and informed consent was obtained from all patients. The study group consisted of 18 women and 12 men with a mean age of 42 years (range 19–64 yrs). The MRI was carried out on average 5 months (range 1–7 mo) after the onset of the first articular pains. Hand (posteroanterior, oblique) and forefoot (anteroposterior, oblique) radiographs were available in all cases and showed no characteristic erosive changes of RA. At the time of the first specialized consultation, the ACR criteria were checked on average 14 months (range 3–36) after the onset of the first articular pains. The median disease duration was 12 months. Medication at entry included nonsteroidal antiinflammatory drugs and corticosteroids in 20 and 3 patients, respectively; none had previously received disease modifying antirheumatic drugs (DMARD). Seven patients were completely untreated.

MRI protocol. MRI was performed with a 1.5 Tesla superconducting magnet (Vision; Siemens, Erlangen, Germany), equipped with a transmit-receive, 20 cm diameter circular surface coil. Both hands were first imaged. The patients underwent imaging in prone or supine position, with the arms semiflexed above the head and the hands positioned in the center of the coil. Straps kept the palms facing each other in "prayer position" and the fingers extended. Intravenous bolus injection of gadolinium-DTPA (0.1 mmol/kg body weight; Dotarem, Guerbet, Roissy, France) was performed after completion of the initial coronal scout view. In all patients, the imaging protocol consisted of fat suppressed gadolinium enhanced T1-weighted spin-echo axial images and gadolinium enhanced 3-dimensional (3D) FLASH (fast low angle shot) axial images. On T1 weighted spin-echo examination, the imaging variables were repetition time (TR) 855 ms, echo time (TE) 20 ms, field of view 15 × 20 cm, section thickness 4 mm with no intersection gap, one signal acquired, matrix 379 × 512, and time of acquisition 5 min 27 s. A total of 16 sections were obtained with this sequence. The FLASH sequence employed frequency-selective water excitation. A 45 mm slab was partitioned into 60 axial sections, resulting in a slice thickness of 1.5 mm. Other imaging variables were TR 36 ms, TE 9 ms, flip angle 50°, field of view 20 × 20 cm, one signal acquired, matrix 300 × 512, and time of acquisition 5 min 25 s. Axial slices consisted of 2 simultaneous series (2 × 8 and 2 × 30 sections with spin-echo and FLASH sequences, respectively). The first series covered the wrists from the distal radioulnar joints to the metacarpal bases and the second one the metacarpophalangeal (MCP) joints. Both feet were then scanned: patients were placed in the

From the Department of Musculoskeletal Radiology and Department of Rheumatology, Hopital Roger Salengro, Lille, France.

N. Boutry, MD; A. Lardé, MD; F. Lapègue, MD; A. Cotten, MD, Department of Musculoskeletal Radiology; E. Solau-Gervais, MD, R-M. Flipo, MD, Department of Rheumatology.

Address reprint requests to Dr. N. Boutry, Radiologie Osteo-Articulaire, Hopital Roger Salengro, Boulevard du Pr. J. Leclerq, 59037 Lille cedex, France.

Submitted January 31, 2002; revision accepted September 19, 2002.

supine position with a small pad under the knees for the duration of the examination. In all patients, postcontrast fat suppressed spin-echo T1 (2 × 8 slices) followed by 3D FLASH (2 × 30 slices) axial images were obtained through the MTP joints. The overall examination time was about 30 minutes.

Analysis of MR images. Two experienced musculoskeletal radiologists (AC and AL) independently reviewed MR images. The patients' identities were unknown and for each patient, scoring of MR images of both hands and the feet was done separately. In cases of interobserver difference, a consensus was achieved. MR images were analyzed for synovitis, tenosynovitis, and bone erosions. Each variable (active synovitis, tenosynovitis, bone erosion) was scored as absent (0) or present (1).

MRI criteria were similar to those described in the literature[1,12,13]. Active synovitis was judged to be positive when periarticular marked enhancement and synovial thickening (greater than the width of the joint capsule) were seen. Tenosynovitis was considered to be present when marked enhancement was seen in the tendon sheath. A distinctive bone defect with a cortical break was defined as a bone erosion. Erosions were scored on MRI at 14 sites within the carpus (distal ulna, distal radius, scaphoid, lunate, triquetrum, pisiform, trapezium, trapezoid, capitate, hamate, and 2nd–5th metacarpal bases). Each MCP joint quadrant (radial, volar, palmar, dorsal) from 2nd to 5th MCP joints and each MTP joint quadrant (lateral, medial, dorsal, plantar) from 1st to 5th MTP joints were evaluated for bony changes. In total, MRI evaluated 60 wrist joints, 240 MCP joints, and 300 MTP joints.

MR images of the same patients presented in a randomized fashion to the reviewers were interpreted twice, with an interval of 7–20 months (mean 15 mo) between the 2 interpretations to determine the intraobserver reliability.

Statistical analysis. A paired Student t test was used to compare MR appearance in the MCP joints and MTP joints and to evaluate differences between MCP and MTP joints. A p value < 0.05 indicated a significant difference. For assessment of intraobserver reliability, kappa statistics were employed on all variables. Kappa values can be interpreted as follows: 0.0–0.20: poor, 0.20–0.40: fair, 0.40–0.60: moderate, 0.60–0.80: good, 0.80–1.00: excellent.

RESULTS

Hands. In the wrists, active synovitis was observed in 53 joints in 28 patients (93%). Periarticular enhancement was seen on MR images in 178 MCP joints in 27 patients (90%) (Figure 1). The 2nd (n = 54) and the 3rd (n = 53) MCP joints were the most frequently involved. Observers found 120 erosions in 24 patients (80%) in the wrists (Figure 2) and 57 erosions in 23 patients (77%) in the MCP joints. In the wrists, the most common sites for erosions were triquetrum (n = 19), capitate (n = 17), lunate (n = 12), scaphoid (n = 10), and trapezoid (n = 10) (Figure 3). The radial aspect of the MCP joints was more frequently involved with erosions ($p < 0.05$), the 3rd (n = 26) and 2nd (n = 14) MCP joints being more affected ($p < 0.05$) (Figure 3). Synovitis was bilateral in 27 patients (90%), whereas bone erosions were bilateral in 21 patients (70%). MR imaging detected tenosynovitis in 16 patients (53%) (Figure 2). The most common sites for tendon involvement were the flexor digitorum (n = 54), extensor digitorum (n = 30), extensor carpi ulnaris (n = 19), and extensor carpi radialis (n = 10) tendons. One patient exhibited a partial thickness tear of the extensor carpi ulnaris tendon.

Feet. Synovitis was seen in 226 MTP joints in 29 patients (97%). MR images revealed this frequency of involvement: 5th MTP joint was involved 50 times, 4th MTP joint 46 times, 3rd MTP joint 45 times, 1st MTP joint 43 times, and

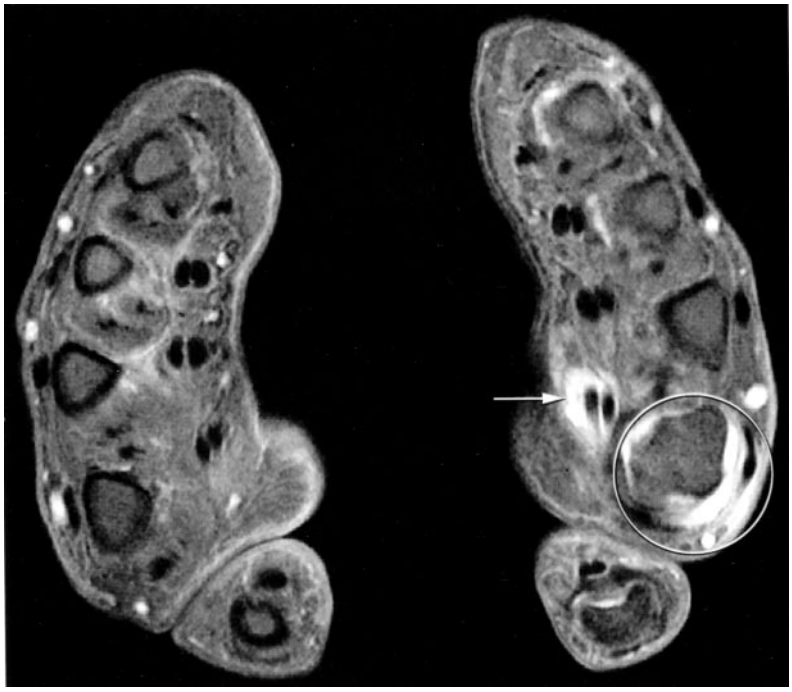

Figure 1. Axial fat suppressed gadolinium enhanced SE T1 weighted MR image in a 53-year-old woman with early RA shows unilateral synovitis in the 2nd left MCP joint (circle). Note also the presence of flexor digitorum synovitis (arrow).

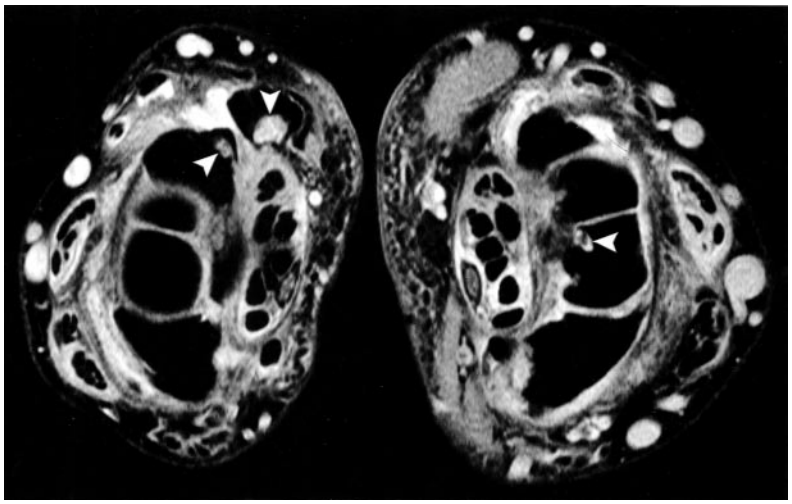

Figure 2. Axial fat suppressed gadolinium enhanced 3D FLASH MR image in a 46-year-old man with early RA reveals carpal bone erosions (arrowheads). Synovitis in the carpal joints and flexor and extensory digitorum tenosynovitis are also evident.

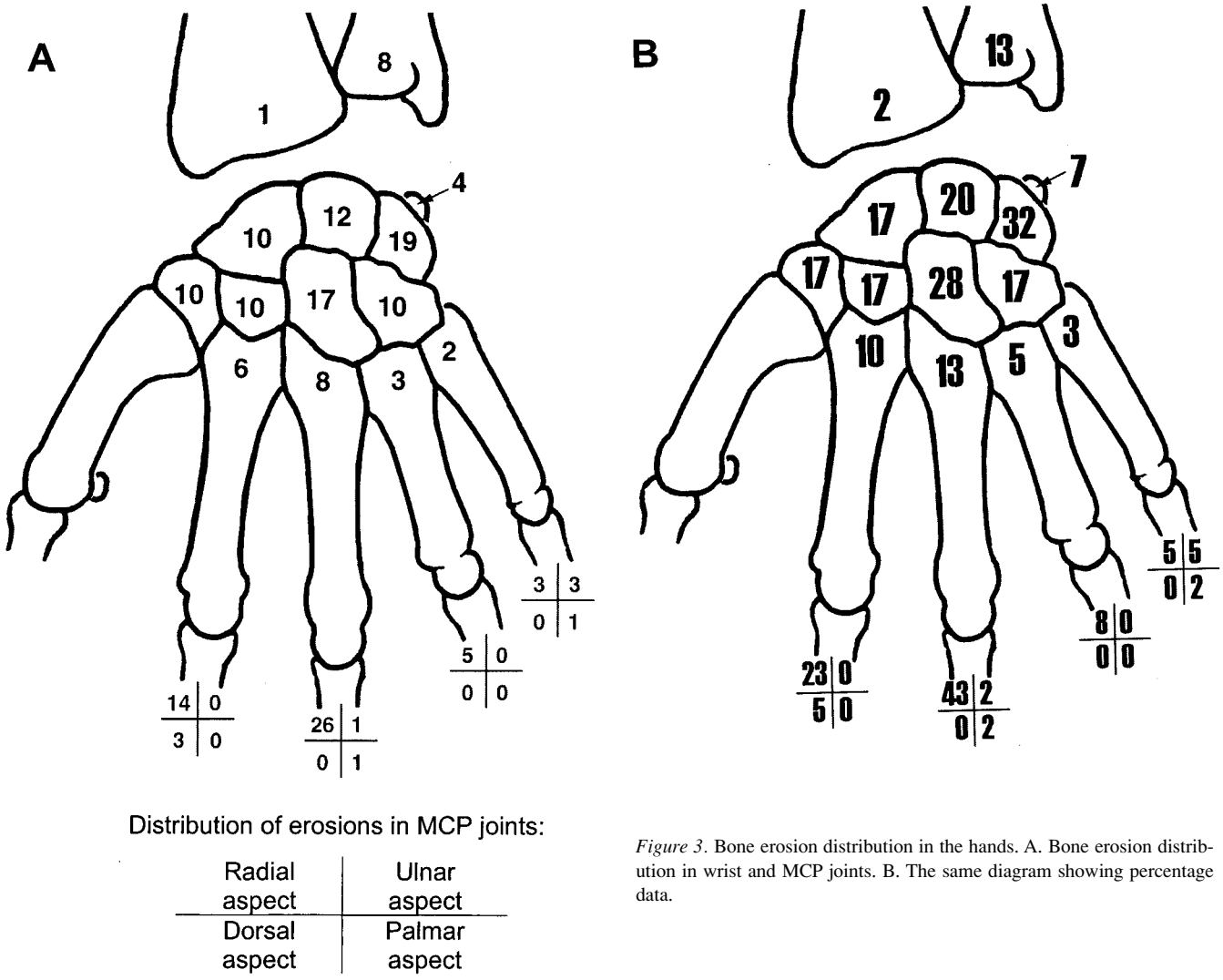

Figure 3. Bone erosion distribution in the hands. A. Bone erosion distribution in wrist and MCP joints. B. The same diagram showing percentage data.

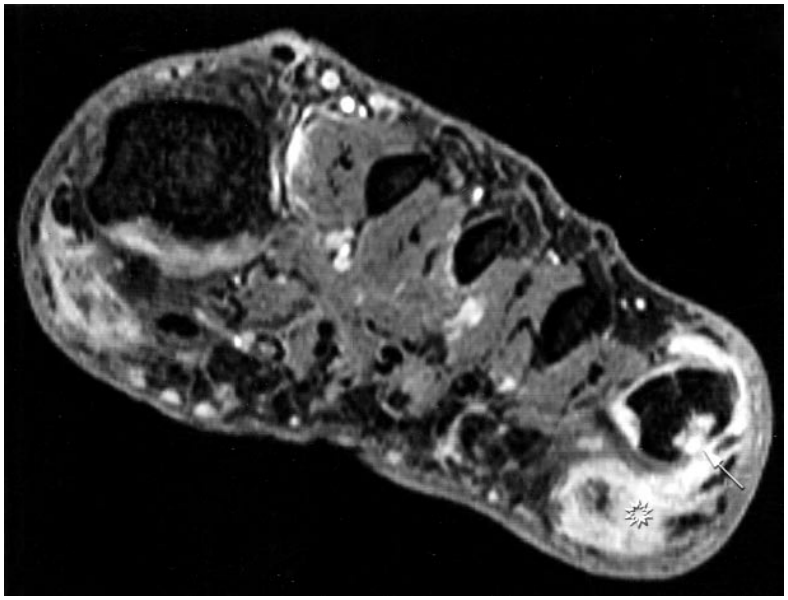

Figure 4. Axial fat suppressed gadolinium enhanced 3D FLASH MR image in a 69-year-old woman with RA shows an osseous erosion on the lateral aspect of the 5th MTP joint (arrow) associated with synovitis. Note the presence of bursitis beneath the 5th metatarsal head (star) and to a lesser degree beneath the 1st metatarsal head.

the 2nd MTP joint 42 times. However, no significant differences were found between the MTP joints. Observers detected 84 bone erosions in 23 patients (77%). The most common sites of erosions were the lateral aspect of the 5th MTP (n = 15) (Figures 4, 7A), the medial aspect of the 1st MTP (n = 10), the plantar aspect of the 1st MTP (n = 7), and the lateral aspect of the 3rd MTP (n = 6) joints (Figure 5). The number of bone erosions was significantly ($p < 0.05$) greater on the lateral aspect of the 5th MTP joint. In 2 patients, erosions were seen in the sesamoid bones (medial, n = 2; lateral, n = 1). Synovitis was bilateral in 28 patients (93%) whereas bone erosions were bilateral in 25 patients (83%).

MR images revealed 90 examples of bursitis in 19 patients (63%). Intermetatarsal bursitis was seen 53 times, mainly in the 3rd (n = 25) and 2nd (n = 20) web spaces (Figure 7B). The prevalence of intermetatarsal bursitis was significantly higher in the 3rd and 2nd spaces ($p < 0.05$) compared to the other web spaces. A bursitis was recorded beneath the metatarsal heads 37 times, located as follows: 1st metatarsal head, n = 12; 5th metatarsal head, n = 8, 2sd metatarsal head, n = 7; 4th metatarsal head, n = 6 and 3rd metatarsal head, n = 4 (Figure 4). The number of submetatarsal bursitis was not statistically different among the toes. According to both observers, tenosynovitis was present in 18 patients (60%). Flexor digitorum tendons (n = 41) were more frequently involved than the extensor (n = 15) ones (Figure 6).

Hands versus feet. In one patient, active synovitis was seen only in the hand joints. In another patient, synovitis was diagnosed only in the feet joints. Six patients had bone erosions in the hands (wrist joints, n = 3 ; MCP joints, n = 3) without bony changes in the feet. Two patients had isolated osseous abnormalities in the feet (Figure 7). There was no significant differences between MCP and MTP joints in terms of bony changes and tenosynovitis. Conversely, synovitis was significantly higher in the MTP joints ($p < 0.05$).

Intra-observer reliability. Intra-observer reliability values showed excellent agreement ($\kappa = 0.86$ for hands, $\kappa = 0.83$ for feet, and overall $\kappa = 0.85$).

DISCUSSION

In our study, MR features of MTP joints in early RA included synovitis (97%) and bone erosions (77%), the 5th MTP joint being the most frequently involved. Also present were bursitis (63%) developed either between or beneath the metatarsal heads and tenosynovitis (60%). Erosive changes were equally prominent in the MCP and MTP joints.

Recently, wrist and finger joint MR imaging has become established as a valuable technique in early detection of bone erosions in RA. A variety of hand imaging techniques have been described in the literature. Some groups [12-16] chose to only evaluate the most symptomatic hand or the dominant hand at the side of the body in a whole-body system. Such assessment is more comfortable for the patient but may lead to false-negative diagnoses in case of unilateral involvement. Circular surface[16] or wrap-around[13] receive-only coils can be used, allowing greater anatomical coverage (from the wrist to the PIP joints) and shorter imaging time, but at the expense of signal-to-noise ratio and homogeneity. McQueen et al.[12,15] preferred to selectively evaluate the wrist joints by means of a dedicated coil with

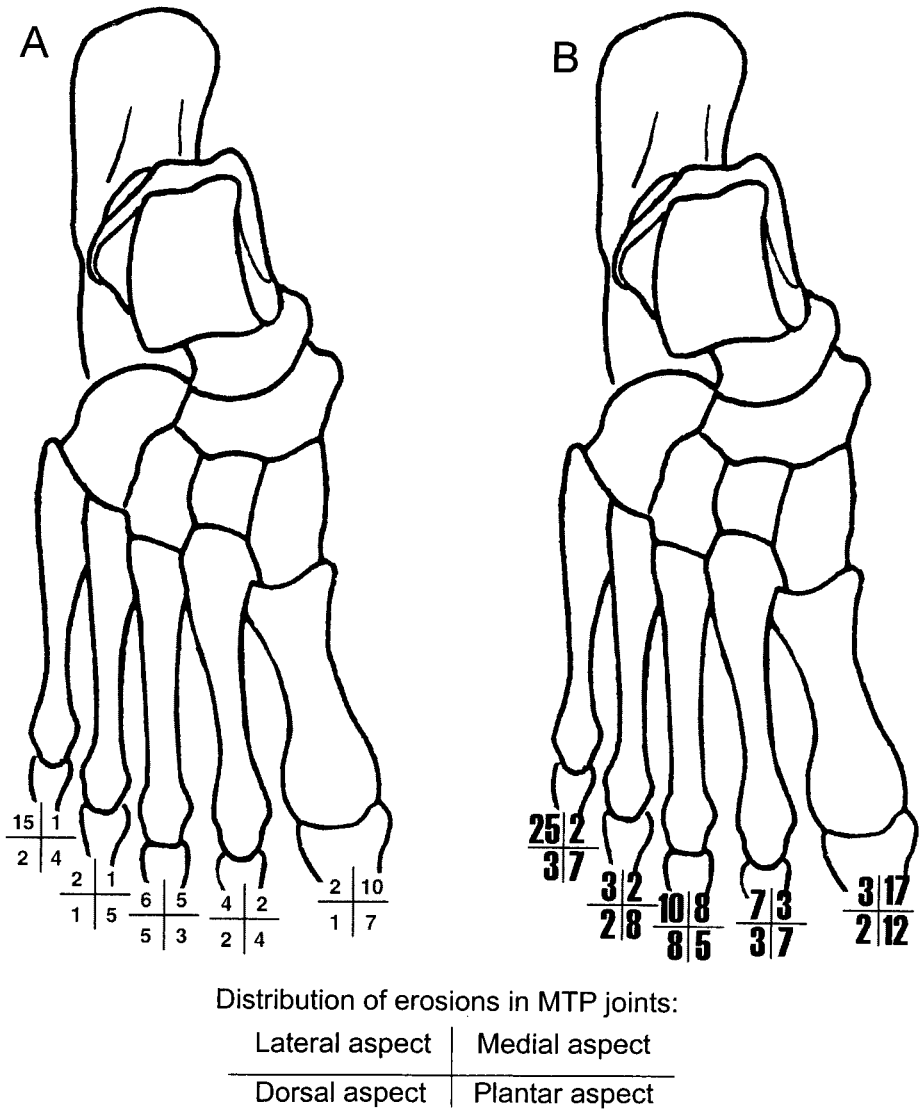

Figure 5. Bone erosion distribution in the feet. A. Bone erosion distribution in MTP joints. B. The same diagram showing percentage data.

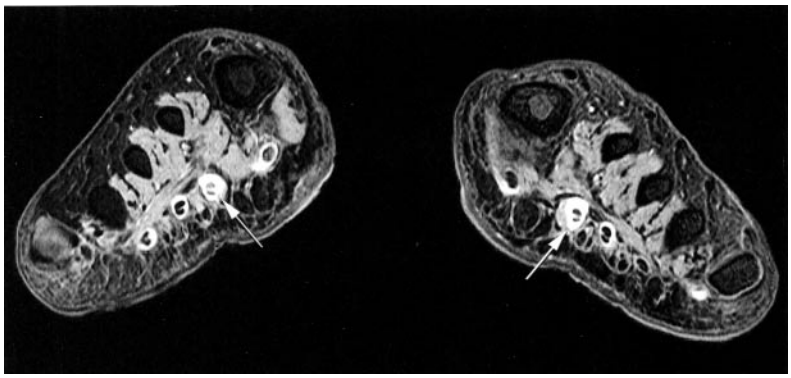

Figure 6. Axial fat suppressed gadolinium enhanced 3D FLASH MR image of MTP joints in a 29-year-old woman with early RA shows bilateral flexor digitorum tenosynovitis (arrows).

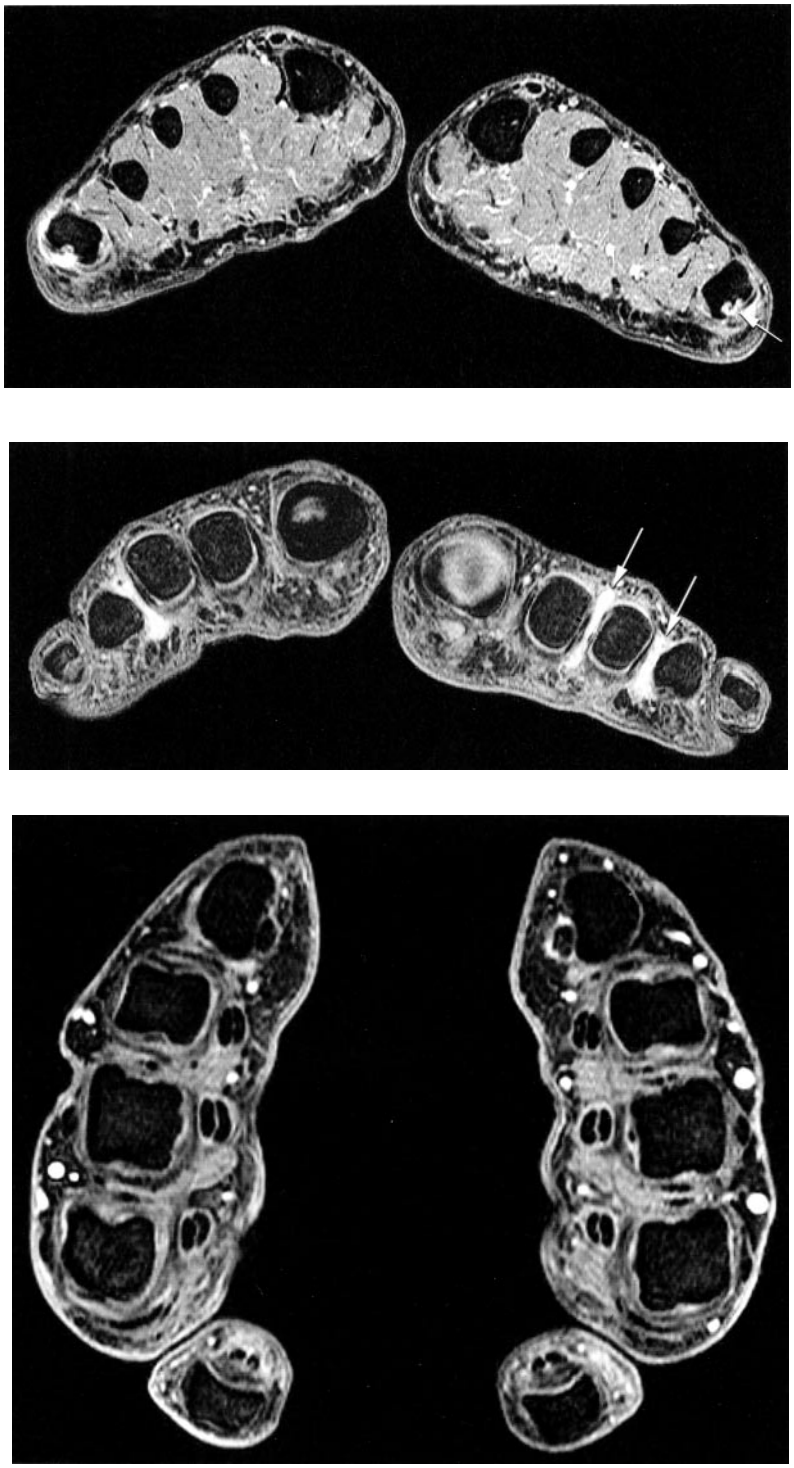

Figure 7. Axial fat suppressed gadolinium enhanced 3D FLASH MR image of MTP joints in a 45-year-old man with early RA reveals bilateral osseous erosions on the lateral aspect of the 5th metatarsal head (arrow) (A), as well as intermetatarsal bursitis (arrows) (B). No abnormality was found in the wrist and MCP joints (C).

opposite advantages and drawbacks. Sugimoto et al.[1,3] studied both hands on separate days. However, besides the cost associated with two imaging sessions, such examination may be difficult to plan in practice. In the present study, we opted for the simultaneous examination of both hands, wrists and forefeet by MR imaging. The over-the-head posi-

tion implies some discomfort for the patient but is less time-consuming. Moreover, the FLASH sequence that we used provided a good spatial resolution (0.39 x 0.39 x 1.5 mm) with respect to acquisition time.

Synovitis can be easily diagnosed with MR imaging. Since rheumatoid pannus is hypervascular, numerous studies have shown that intravenous administration of contrast material allows distinction between synovial proliferation and joint effusion[17-19]. It also should be emphasized that fat suppression techniques reveal synovitis better than standard MR imaging techniques[20,21]. In this study, we imaged the joints with fat-suppressed T1-weighted SE MR imaging straightaway after a bolus intravenous injection of Gd-DTPA. Thus, enhanced structures were adequately depicted without needed comparison with nonenhanced images. We also saved time to obtain the 15 minute-delayed images of the feet.

Fat suppressed gadolinium-enhanced T1-weighted spin-echo imaging has reportedly[17,19] been used to detect active synovitis in RA hand joints. In Huh's study[21] however, a contrast enhanced, fat-suppressed 3D gradient-echo sequence (SPGR) was performed to assess synovial inflammation in patients who received DMARDs. These authors found significant differences in terms of inflamed synovial volume between the remission and the non-remission groups. In the present study, we used a 3D-FLASH sequence (which is similar to the SPGR one) with water excitation for detection of bone erosions. In contrast to the frequency-selective presaturation, a more uniform fat suppression can be achieved in the distal extremities[22] with the water excitation technique.

In Sugimoto's study[1], the diagnosis of active synovitis was based on evidence of periarticular contrast material enhancement in both hands on spin-echo MR imaging. The same authors[3] showed that the introduction of this MR imaging criterion into the 1987 ARA revised criteria could improve diagnostic performance in patients who are suspected of having early RA. However, contrast enhancement is nonspecific[23,24]. Sugimoto et al.[1] found three false-positive diagnoses (cryoglobulinemia, viral arthritis, and Behçet syndrome). Furthermore, there are some early RA cases with unilateral involvement of the hands. In this regard, it is noteworthy that three patients with RA had unilateral hand joint enhancement in our series.

Erosive bony changes are more specific of early RA than synovitis. Once again, MR imaging has been shown to be more sensitive than plain radiography for the detection of bone abnormalities[14,25,26]. The synovial proliferation primarily affects the joint and bone damage result from synovitis[26]. Several studies, however, have suggested that erosions occur in very early RA[15,27,28]. McQueen et al.[12] found a carpal erosion prevalence of 45% on MR images at only four months after symptom onset. In Klarlund's study[29], MRI detected bone erosions of the MCP and proximal interphalangeal (PIP) joints in 50% of patients. McGonagle et al.[28] reported a higher MR prevalence of bone damage (95%) in the worst affected hand in RA patients with symptoms for less than 1 year. In our series, the prevalence of bone erosions on average 5 months after the onset of the first symptoms was high as well, both in the wrists (80% of patients) and the MCP joints (77% of patients). In contrast to Mc Queen[12] and Klarlund[29] however, we used a thin-partition 3D MR imaging which probably allowed a more accurate assessment of bone abnormalities. Moreover, at only one year follow up, Mc Queen et al.[15] found that a higher proportion of RA patients had developed MRI erosions in the wrists (74%).

In some reports[7,12], the capitate is the most common site for erosion. Although it was frequently involved in our study (n = 17), the triquetrum (n = 19) was more frequently damaged, consistent with Klarlund's observations[13]. The 2nd and 3rd MCP joints are also commonly involved in early RA[7,13], especially on their radial aspect[13]. We observed similar results. In the current study, we identified tenosynovitis in 53% of cases. In accordance with previous reports[7,12,14], MR changes were commonly found in the flexor tendon and extensor carpi ulnaris tendon sheaths.

Different scoring systems of MRI findings have been described[3,12,13,30], all different. The OMERACT group[13] also suggests that bone erosions be visible in coronal and axial planes (when they are available) with a cortical break seen in at least one plane. In the present study, bone erosions have only been scored on axial MR images. On the one hand however, cortical breaks are shown best on thin contiguous slices as we used. On the other hand, we believe that axial slices, in preference to coronal slices, are well suited for reliable scoring of bony changes, especially within the carpus.

Marrow edema-like MR changes have been found to precede the development of frank erosions[12,27]. Moreover, according to McQueen[15], bone edema is a strong individual predictor of bone erosion and carries a 6.5-fold risk of bone damage at the same site within one year. It is also speculated that bone edema may be reversible[4,27]. In the present study, there is no mention of such MR findings, for two reasons: firstly, we did not perform T2-weighted sequences and secondly, we used gradient-echo sequences which are well known for being less sensitive than spin-echo sequences in detecting bone edema.

Conventional radiography changes affecting the feet in early RA are well recognized. Bone erosions may reportedly develop earlier in the foot than in the hand joints[9,10] and furthermore, the feet may be more affected than the hands[8]. In view of this, MR imaging of the feet has potential applications in early RA diagnosis. To our knowledge however, no other series has been published describing the MR findings of early RA in the feet or comparing hand and foot involvement. In 97% of cases, MR imaging findings were consistent with the presence of active synovitis in the MTP

joints. Previous studies[31,32] suggested that MR image acquisition should be performed quickly after gadolinium contrast injection (6-11 minutes) to allow better delineation of synovium from joint effusion, especially when quantifying the volume of inflamed synovial membrane is required. In our series therefore, we are aware that an overestimation of the amount of inflamed synovium may have resulted from the time interval between contrast agent injection and MR images acquisition. However, both synovial thickening and effusion are expressions of the same process in RA. Moreover, regarding active synovitis, we always took into account both criteria of synovial enhancement and synovial cavity distension. In this respect, comparison with the other MTP joints, on the same side and on the opposite side, was particularly useful.

In agreement with radiographic data, the lateral aspect of the 5th MTP joint exhibited the largest number of erosions. Conversely, the medial aspect of the 5th MTP joint was involved only one time. The 1st MTP joints were commonly affected in our series. However, this latter finding also is evident in osteoarthritis. Interestingly, bursitis was a common finding. Although the prevalence of such MR findings in controls is not clear, especially at the great toe, their recognition may constitute an additional predictor of early RA.

In contrast to would have been expected from plain radiographs, we did not find more bone erosions in the MTP than in the MCP joints. Furthermore, 6 patients had erosive changes in the hands only, 3 of whom in the MCP joints. However, further studies in a larger patient population and MR assessment of midfoot joints are clearly required. The 2 patients with isolated bony changes in the feet are especially noteworthy. Consequently, additional MR imaging of the feet may be useful when evaluation of the hands does not help identify early RA.

This study does have limitations. First, the number of patients is small. Second, our study was retrospective with an inherent selection bias that did not allow assessment of the frequency with which synovitis, bone erosions, bursitis and tenosynovitis affect patients with inflammatory polyarthralgia.

In conclusion, MR features of early RA in the feet include active synovitis (97%), bone erosions (77%), bursitis (63%) and tenosynovitis (60%). Erosions predominate on the lateral aspect of the 5th MTP joint. Bursal inflammation between or beneath the metatarsal heads is a common MR finding. Patients with early RA exhibit as many bony changes in the MTP as in the MCP joints. MR imaging of the feet may be a helpful adjunct to hand evaluation in equivocal cases.

REFERENCES

1. Sugimoto H, Takeda A, Masuyama J, Furuse M. Early-stage rheumatoid arthritis: diagnostic accuracy of MR imaging. Radiology 1996;198:185-92.
2. McQueen FM. Magnetic resonance imaging in early inflammatory arthritis: what is its role? Rheumatology 2000;39:700-6.
3. Sugimoto H, Takeda A, Hyodoh K. Early-stage rheumatoid arthritis: prospective study of the effectiveness of MR imaging for diagnosis. Radiology 2000;216:569-75.
4. Peterfy CG. Magnetic resonance imaging in rheumatoid arthritis: current status and future directions. J Rheumatol 2001;28:1134-42.
5. Goupille P, Roulot B, Akoka S, Avimadje AM, Garaud P, Naccache L, et al. Magnetic resonance imaging: a valuable method for the detection of synovial inflammation in rheumatoid arthritis. J Rheumatol 2001;28:35-40.
6. Jevtic V, Watt I, Rozman B, Kos-Golja M, Rupenovic S, Logar D, et al. Precontrast and postcontrast (Gd-DTPA) magnetic resonance imaging of hand joints in patients with rheumatoid arthritis. Clin Radiol 1993;48:176-81.
7. Pierre-Jerome C, Bekkelund SI, Mellgren SI, Torbergsen T, Husby G, Nordstrom R. The rheumatoid wrist: bilateral MR analysis of the distribution of rheumatoid lesions in axial plan in a female population. Clin Rheumatol 1997;16:80-6.
8. van der Heijde DM, van Leeuwen MA, van Riel PL, Koster AM, van't Hof MA, van Rijswijk MH et al. Biannual radiographic assessments of hands and feet in a three-year prospective followup of patients with early rheumatoid arthritis. Arthritis Rheum 1992;35:26-34.
9. Brook A, Corbett M. Radiographic changes in early rheumatoid disease. Ann Rheum Dis 1977;36:71-3.
10. Resnick D, Niwayama G. Rheumatoid arthritis. In: Diagnosis of bone and joint disorders, 3rd Edition. Philadelphia: WB Saunders;1995:866-970.
11. Arnett FC, Edworthy SM, Bloch DA, McShane DJ, Fries JF, Cooper NS et al. The American Rheumatism Association 1987 revised criteria for the classification of rheumatoid arthritis. Arthritis Rheum 1988;31:315-24.
12. McQueen FM, Stewart N, Crabbe J, Robinson E, Yeoman S, Tan PL, et al. Magnetic resonance imaging of the wrist in early rheumatoid arthritis reveals a high prevalence of erosions at four months after symptom onset. Ann Rheum Dis 1998;57:350-6.
13. Conaghan P, Edmonds J, Emery P, Genant H, Gibbon W, Klarlund M, et al. Magnetic resonance imaging in rheumatoid arthritis: summary of OMERACT activities, current status, and plans. J Rheumatol 2001;28:1158-62.
14. Backhaus M, Kamradt K, Sandrock D, Loreck D, Fritz J, Wolf KJ, et al. Arthritis of the finger joints: a comprehensive approach comparing conventional radiography, scintigraphy, ultrasound, and contrast-enhanced magnetic resonance imaging. Arthritis Rheum 1999;42:1232-45.
15. McQueen FM, Stewart N, Crabbe J, Robinson E, Yeoman S, Tan PLJ, et al. Magnetic resonance imaging of the wrist in early rheumatoid arthritis reveals progression of erosions despite clinical improvement. Ann Rheum Dis 1999;58:156-63.
16. Savnik A, Malmskov H, Thomsen HS, Graff LB, Nielsen H, Danneskiold-Samsoe B, et al. MRI of the wrist and finger joints in inflammatory joint diseases at 1-year interval: MRI features to predict bone erosions. Eur Radiol 2002;12:1203-10.
17. Kursunoglu-Brahme S, Riccio T, Weisman MH, Resnick D, Zvaifler N, Sanders ME, et al. Rheumatoid knee: role of gadopentetate-enhanced MR imaging. Radiology 1990;176:831-5.
18. Konig H, Sieper J, Wolf KJ. Rheumatoid arthritis: evaluation of hypervascular and fibrous pannus with dynamic MR imaging enhanced with Gd-DTPA. Radiology 1990;176:473-7.
19. Bjorkengren AG, Geborek P, Rydholm U, Holtas S, Petterson H. MR imaging of the knee in acute rheumatoid arthritis: synovial uptake of gadolinium-DOTA. AJR 1990;155:329-32.
20. Nakahara N, Uetani M, Hayashi K, Kawahara Y, Matsumoto T, Oda J. Gadolinium-enhanced MR imaging of the wrist in rheumatoid

arthritis: value of fat suppression pulse sequences. Skeletal Radiol 1996;25:639-47.
21. Huh YM, Suh JS, Jeong EK, Lee SK, Lee JS, Choi BW et al. Role of the inflamed synovial volume of the wrist in defining remission of rheumatoid arthritis with gadolinium-enhanced 3D-SPGR MR imaging. J Magn Reson Imaging 1999;10:202-8.
22. Maas M, Dijkstra PF, Akkerman EM. Uniform fat suppression in hands and feet through the use of two-point Dixon chemical shift MR imaging. Radiology 1999;210:189-93.
23. Tonolli-Serabian I, Poet JL, Dufour M, Carasset S, Mattei JP, Roux H. Magnetic resonance imaging of the wrist in rheumatoid arthritis: comparison with other inflammatory joint diseases and control subjects. Clin Rheumatol 1996;15:137-42.
24. Reiser MF, Bongartz GP, Erlemann R, Schneider M, Pauly T, Sittek H et al. Gadolinium-DTPA in rheumatoid arthritis and related diseases: first results with dynamic magnetic resonance imaging. Skeletal Radiol 1989;18:591-7.
25. Foley-Nolan D, Stack JP, Ryan M, Redmond U, Barry C, Ennis J, et al. Magnetic resonance imaging in the assessment of rheumatoid arthritis – a comparison with plain film radiographs. Br J Rheumatol 1991;30:101-6.
26. Corvetta A, Giovagnoni A, Baldelli S, Ercolani P, Pomponio G, Luchetti MM. MR imaging of rheumatoid hand lesions: comparison with conventional radiology in 31 patients. Clin Exp Rheumatol 1992;10:217-22.
27. McGonagle D, Conaghan PG, O'Connor P, Gibbon W, Green M, Wakefield R, et al. The relationship between synovitis and bone changes in early untreated rheumatoid arthritis. Arthritis Rheum 1999, 42:1706-11.
28. McGonagle D, Green MJ, Proudman S, Richardson C, Veale D, O'Connor P, et al. The majority of patients with rheumatoid arthritis have erosive disease at presentation when magnetic resonance imaging of the dominant hand is employed. Br J Rheumatol 1997;36 Suppl 1:121.
29. Klarlund M, Ostergaard M, Jensen KE, Madsen JL, Skjodt H, Lorenzen I, et al. Magnetic resonance imaging, radiography, and scintigraphy of the finger joints: one year follow up of patients with early arthritis. The TIRA group. Ann Rheum Dis 2000;59:521-8.
30. Ostergaard M, Klarlund M, Lassere L, Conaghan P, Peterfy C, McQueen F, et al. Interreader agreement in the assessment of magnetic resonance images of rheumatoid arthritis wrist and finger joints – an international multicenter study. J Rheumatol 2001;28:1143-50.
31. Ostergaard M, Klarlund M. Importance of timing of post-contrast MRI in rheumatoid arthritis: what happens during the first 60 minutes after IV gadolinium-DTPA? Ann Rheum Dis 2001; 60:1050-4.
32. Huang J, Stewart N, Crabbe J, Robinson E, McLean L, Yeoman S, et al. A 1-year follow-up study of dynamic magnetic resonance imaging in early rheumatoid arthritis reveals synovitis to be increased in shared epitope-positive patients and predictive of erosions at 1 year. Rheumatology 2000;39:407-16.