Identification of Wrist and Metacarpophalangeal Joint Erosions Using a Portable Magnetic Resonance Imaging System Compared to Conventional Radiographs

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ABSTRACT. ***Objective.*** To compare magnetic resonance (MR) images obtained using a portable MR system to radiographs for identifying bone erosions in the wrists and metacarpophalangeal (MCP) joints of patients with inflammatory arthropathy.

Methods. MR imaging and radiographs were performed in wrists (n = 227) and 2nd and 3rd MCP (n = 188) of 132 patients with inflammatory arthritis to identify erosions. MR imaging was performed using a portable MR system. Findings per body location and per patient were calculated and compared. Additionally, intraobserver and interobserver reliabilities were calculated.

Results. MR imaging identified bony erosions in 125 (95%) patients and in 315 (78%) body locations. By comparison, radiographs identified erosions in 78 (59%; $p < 0.05$) patients and in 156 (39%; $p < 0.05$) body locations. Intraobserver reliability (K = 0.564) and interobserver reliability (K = 0.429) exhibited moderate agreement, with reader agreement in 80% of the joints scored.

Conclusion. There was superior sensitivity to bone damage using the portable MR system compared to radiographs of the wrists and MCP joints, suggesting that this scanner is extremely promising for assessment of inflammatory arthritis. (J Rheumatol 2004;31:676–85)

Key Indexing Terms:
MAGNETIC RESONANCE IMAGING   MAGNETIC RESONANCE
COMPARATIVE STUDIES   WRIST   HAND   RHEUMATOID ARTHRITIS

Rheumatoid arthritis (RA) is a chronic autoimmune inflammatory disorder of unknown etiology that occurs in roughly 1% of the adult population[1]. Physical impairment associated with RA results from synovial inflammation causing pain, stiffness, swelling, and marginal bone erosions of affected joints[1-5]. In RA, the patient's wrists, hands, and feet are predominantly affected in a symmetrical manner, a characteristic usually not found in other forms of arthritis[1,6,7].

The diagnosis and assessment of aggressive RA, especially in the early stages of this progressive disorder, is a challenging problem for the practicing clinician. Notably, significant damage occurs during the first 2 years after disease onset[1,8]. Early therapeutic intervention is believed to retard or prevent joint destruction[9-13]. Therefore rapid recognition and treatment of RA is considered to be particularly crucial for an optimal clinical outcome[10-13].

One of the few objective criteria used for diagnosis and followup of RA is the standard radiograph[4,6]. Radiographic changes in the wrist, finger, and toe joints are a useful indicator of overall joint damage in RA[14], with the wrist, metacarpophalangeal (MCP), proximal interphalangeal (PIP), and metatarsophalangeal (MTP) joints most frequently involved in early RA[14-16]. Unfortunately, the use of radiography has major limitations when used to assess RA. For example, patients may have long periods of active, symptomatic disease while radiographs remain normal or show only nonspecific changes[16-18]. On the other hand, it is recommended that all patients be followed radiographically, as bony changes have been shown to progress to debilitating levels even in patients exhibiting minimal symptoms[19]. Thus, an economical, yet more sensitive and accurate imaging technique for erosive pathology would be a major benefit in the management of patients with RA.

There is growing evidence that magnetic resonance (MR) imaging is sensitive and accurate for identifying various structural changes associated with RA and for staging therapeutic response[16,17,20-34]. Bony erosion is a critical finding in the diagnosis and assessment of RA. Several investigations have reported that MR imaging is highly sensitive for detecting erosions in the hands and wrists of patients with RA[20,21,25-28,32-34]. Indeed, erosions shown by MR imaging

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may be visible 6 to 12 months or more before being observed on radiographs[16,20-28,32-34], providing a means of early detection for immediate therapeutic intervention.

The pharmaceutical industry has made great progress in the development of new biologic disease-modifying therapies that inhibit erosions and progressive joint destruction in inflammatory arthritis[9-12]. For maximum effectiveness, patients should begin therapy before significant bone destruction occurs[11,12]. However, clinical efficacy is hampered by the poor sensitivity of radiographs to detect early erosive disease, as well as the inability of radiographs to reveal response to disease-modifying antirheumatic drug (DMARD) therapy in a timely and accurate manner[17]. Therefore a more sensitive indicator of erosive damage is needed to help assess the severity of RA, especially during the initial phase, and to guide and monitor treatment. This would facilitate the use of early, aggressive therapeutic strategies.

The superior sensitivity to early bone damage makes MR imaging of the hand and wrist exceptionally promising in the diagnosis and followup of patients with RA[16,17]. However, because most investigations using MR imaging in RA patients used high field-strength, whole-body MR systems, the examinations were expensive and not readily available to patients in a rheumatology office setting. The expense associated with MR imaging is one of the important limiting factors to more widespread utilization of this diagnostic method. Less expensive, more comfortable, and more convenient alternatives are desirable[17,34]. Recently, a new low cost, portable MR system became available for evaluating extremities. The use of this unique MR system could greatly influence the expense and accessibility of MR imaging for RA patients. To date, there has been no report of the clinical use of this portable MR system. We compared MR images obtained using the portable MR system to radiographs for identifying bone erosions in the wrists and hands of patients with RA. A secondary goal of this study was to determine intra- and interobserver reliability in assessing these joints using MR imaging.

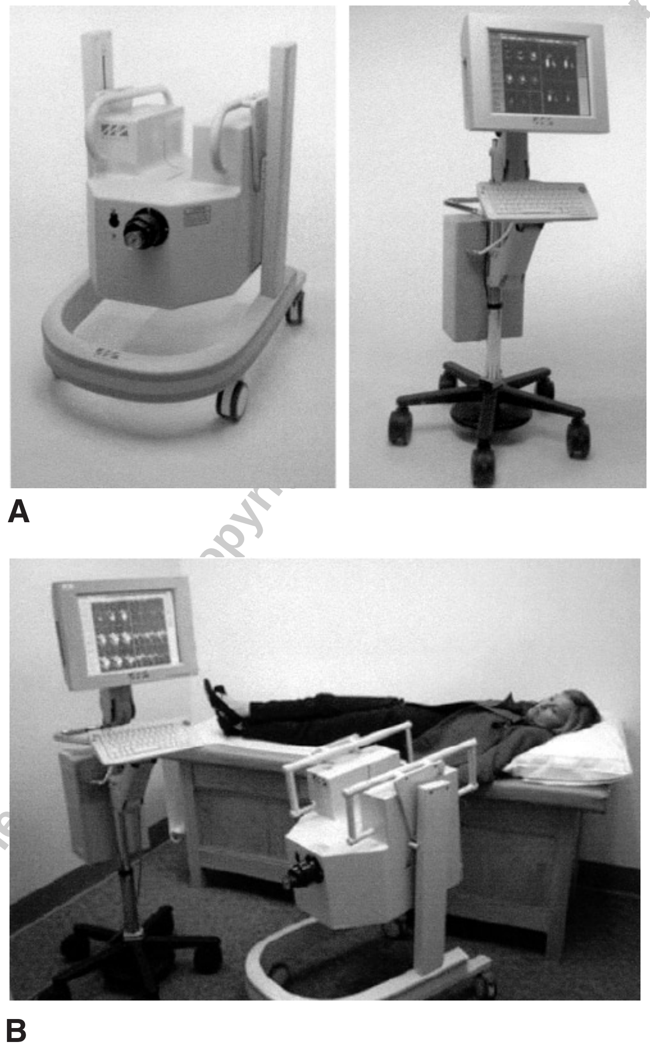


Figure 1. A. Portable MR system designed to image extremities (left, magnet and sensor; right, control console). This self-shielded, low field scanner utilizes a nonhomogeneous magnetic field image acquisition method and occupies a space of 4 m^2. B. The portable MR system positioned to perform MR imaging of the hand and wrist.

MATERIALS AND METHODS

Study subjects. A total of 132 patients (101 women, 31 men; mean age 62 yrs, range 32–88) took part in this study. Ninety-five percent of the patients satisfied the American College of Rheumatology criteria for the diagnosis of RA. The remainder had joint symptoms in the setting of psoriasis. This study group was representative of the typical patient population found in a rheumatology-based clinical practice. The same rheumatologist performed clinical examinations on these patients, which included an assessment of joint swelling and tenderness. For inclusion, the subject had to be 18 years of age or older with no condition that would be contraindicated for MR imaging or radiographic examination[35].

Portable MR system. An inexpensive, portable MR system (MagneVu 1000, MagneVu, Carlsbad, CA, USA) designed to image extremities (i.e., hands, wrists, and feet) was used in this study (Figure 1A). This self-shielded, low-field (0.2 Tesla) scanner utilizes a unique nonhomogeneous magnetic field image acquisition process to perform MR imaging. The gradient system for this device has a rate of change of 30 T/s temporal and spatial peak. Flat transmit/receive radio frequency coils tuned to hydrogen protons are used for imaging. The portable MR system operates on standard 110 V power and has no special air-conditioning requirements. The entire system is relatively lightweight (magnet and sensor, 175 lbs; control console, 125 lbs) and occupies an ordinary office space of approximately 4 m^2 without the need for external radio frequency or magnetic field shielding. The assembly with the permanent magnet can be positioned in a correct orientation to perform the desired imaging procedure (Figure 1B). Further, the system components are separable and mounted on wheels for easy transport. MR imaging capabilities for the portable MR system include 3-dimensional, multiecho data acquisitions for a variety of pulse sequences including proton density, T1, and T2 weighted, spin echo, and inversion recovery (STIR) sequences. Importantly, while the typical low field extremity MR system is limited by a lower spatial resolution[36,37], this is not an issue for the portable MR system, which permits high resolution MR imaging (imaging performance parameters: section thickness, 1 to 10 mm; display matrix 32 × 48 up to 256 × 384; specification volume 50 × 75 × 10 mm; signal-to-noise ratio 50:1; uniformity ≈ 80%; geometric distortion ± 6.5%).

Radiographic and MR imaging examinations. Standard radiographs of the wrists and hands obtained in 3 planes (anteroposterior, oblique, and lateral projections) and MR imaging examinations were performed in each patient. Radiographic examinations were performed a mean of 37 days (range 0 to 202 days) relative to the MR imaging examinations, with 52% obtained the same day as MR imaging.

MR imaging examinations were conducted using T1 weighted spin echo (TR/TE, 100/24 ms; field of view 50 × 75 mm; 2 excitations; 1 mm section thickness, 1 mm coronal in-plane resolution; 3 imaging planes; time 14 min) and STIR pulse sequences (TR/TE/TI, 100/24/50 ms; field of view 50 × 75 mm; 4 excitations; 1 mm section thickness, 1.4 mm coronal in-plane resolution; 3 imaging planes; time 13 min). All interpretations were performed viewing images displayed in the coronal plane.

For the 132 patients, a total of 415 different body locations (based on MR imaging examinations) were included in the comparative analysis, as follows: wrists, n = 227 (55%) and 2nd–3rd MCP joints, n = 188 (45%).

Interpretation. Radiographic and MR imaging examinations were interpreted by 2 board certified radiologists with musculoskeletal reading experience (Reader 1, radiologist with > 17 years of MR musculoskeletal reading experience; Reader 2, radiologist with 4 years of MR musculoskeletal reading experience.) Reader 1 interpreted all studies twice, once at the time the study was performed and again one month after the end of the study period in a single session. Reader 2 interpreted each MR examination once through the course of the study in batches of one to 20 studies at a session. The radiologists interpreted the diagnostic studies in an independent, prospective manner. They had knowledge of the patient's age, sex, and presumptive diagnosis. Radiographs and MR imaging examinations were reviewed to specifically identify the presence of bone erosion. Radiographs were read as hard-copy films on a standard view box. On the radiographic examination, bone erosion was defined as sharply marginated regions of decreased bone density adjacent to an area of cortical interruption, based on standard plain-film radiograph criteria[4,6]. The radiographs were evaluated with the knowledge of the MR findings to assure maximum sensitivity in the radiographic interpretation.

MR images were transferred from the portable MR system (which was based in the rheumatologist's office) via the Internet using encryption software to a computer workstation and read on a monitor. On the MR images, bone erosion was defined as a bone defect with sharp margins, with correct juxtaarticular localization and extension through adjacent cortical bone. Signal characteristics for erosion were low signal intensity with respect to marrow fat on T1 weighted images and high signal intensity on STIR images.

Subclassification of the bone erosion appearance was as follows: "scoop," width equal to or greater than depth like a scoop out of an ice cream container; "tunnel," width less than depth; "dot," lesion in center of bone because the erosion is on the ventral or dorsal aspect of bone; "overhang," thin spicule of bone extending from edge of lesion; and "diffuse," innumerable erosions removing the cortex of bone from the carpal bones. Examples of these subclassifications on MR imaging are provided here as we believe they have interpretive value in differentiating normal bone anatomy from pathology on high resolution MR images, as these patterns were seen in only one joint in 9 healthy volunteers; however, the related clinical significance is currently unknown.

Statistical analysis. The numbers of erosions seen on radiographs and MR images were calculated and compared. Standard statistical definitions and analyses were determined using StatView (SAS Institute Inc., Cary, NC, USA). To determine intraobserver and interobserver reliability, kappa (K) values were calculated[38]. The kappa statistic is a chance-corrected measure of agreement. This variable considers the proportion of observed agreements (P_o) and the proportion of chance agreements (P_c), as follows:

$$K = P_o - P_c / 1 - P_c$$

The following interpretation of kappa values was used[39]: > 0.80 (80%) = excellent; > 0.60 (60%) = substantial; 0.40 (40%) to 0.60 (or 60%) = moderate; and < 0.40 (40%) = fair to poor.

RESULTS

Comparison of radiographs with MR imaging. Technically acceptable MR imaging results were obtained for 403 (97%) of the body locations or 125 (95%) of the patients (i.e., motion artifact problems were seen for 12 examinations). Table 1 displays a summary of findings comparing MR images obtained using the portable MR system to radiographic examinations. MR imaging identified bony erosions in 125 (95%) patients and in 315 (78%) body locations. By comparison, radiographs identified erosions in 78 (59%; $p < 0.05$) patients and in 156 (39%; $p < 0.05$) body locations. Only 6 (1%) of the body locations had positive radiographs and negative MR imaging (one with an extensive deformity associated with old trauma). One hundred sixty-six (41%) of the 403 body locations showed MR imaging evidence of erosions with negative radiographs. Figures 2 to 8 show examples of MR images and radiographs obtained in this study population. Of note is that, for a given body location, a consistently greater number of erosions was seen on MR imaging compared to radiographs (Figures 5 and 8). The morphology and extent of erosions seen on both MR images and radiographs were best determined on the MR images. All bony erosions in this study were bright on the STIR images.

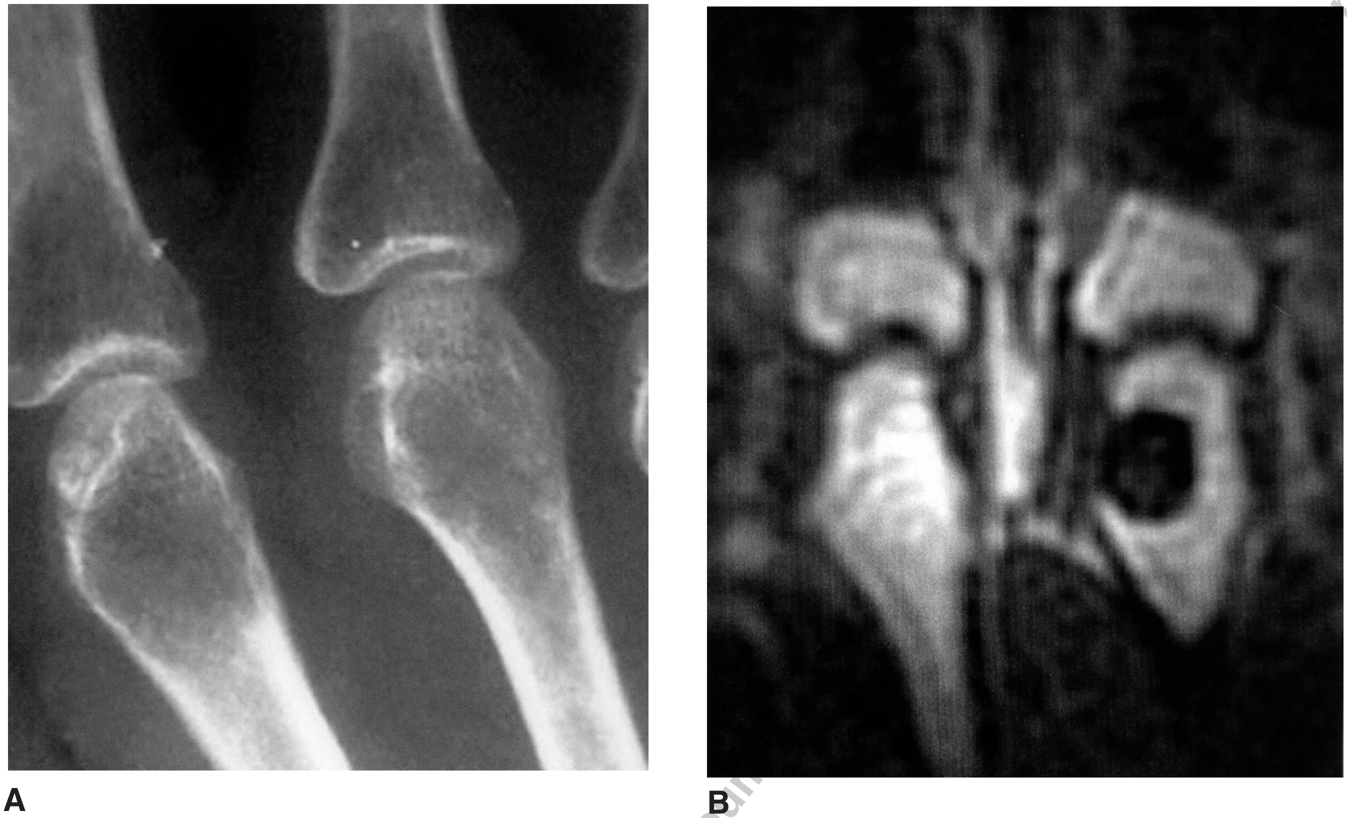
Intra- and interobserver reliability. Comparing MR imaging interpretations for Reader 1, first reading to second reading (intraobserver reliability) resulted in K = 0.564, which represents moderate reliability. However, this reader was reliable in 84% of the cases read. Comparing MR imaging interpretations of Reader 1 to Reader 2 (interobserver reliability) yielded K = 0.429, which represents moderate reliability. This reader was reliable in 80% of the cases read.

DISCUSSION

Reports have indicated that MR imaging is more sensitive in identifying joint damage associated with RA compared to radiographs or clinical examinations[20-34]. With the exception

Table 1. Summary of findings for bony erosions for MR imaging using the portable MR system compared with radiographs in the wrists and MCP joints of patients with RA.

	Number of Bony Erosions Identified	
	MR Imaging	Radiograph
Patients (%)	125 (95)	78 (59)
Locations (%)	315 (78)	156 (39)
MR Imaging and Radiograph Comparison for Body Locations, n = 403 (%)		
MR negative/radiograph negative	81 (20)	
MR negative/radiograph positive	6 (1)	
MR positive/radiograph negative	166 (41)	
MR positive/radiograph positive	150 (37)	



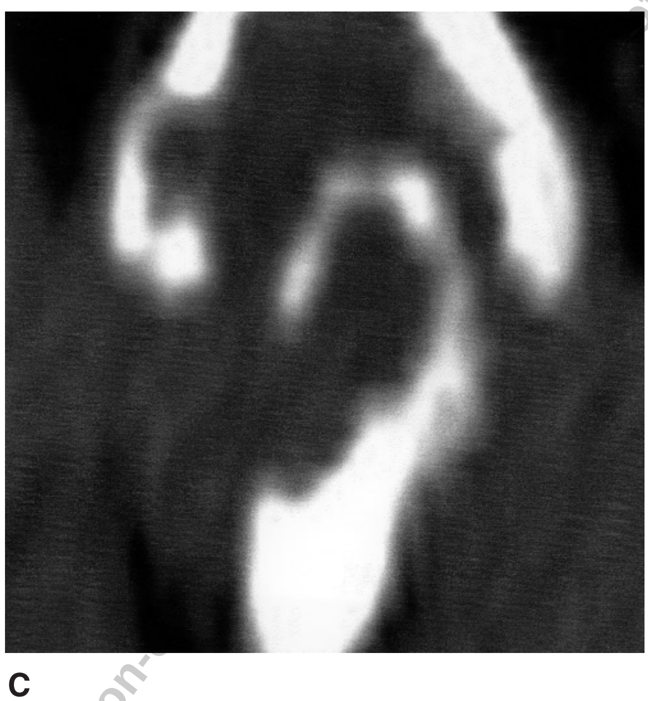


Figure 2. Large occult erosion on radiograph. A. The plain radiograph prospectively did not reveal a third metacarpal head erosion. B. The T1 weighted MR image shows a large region of low signal intensity within the 3rd metacarpal head, typical of an erosion. C. The computer tomography coronal reconstruction confirms the cortical erosion not visible on the plain radiograph.

of one investigation[34], most of this research was conducted using high field-strength MR systems. We used an office-based, portable MR system MR to assess wrists and MCP joints of patients with RA. We found that MR imaging using this scanner detected erosions in 125 patients (315 body locations), whereas radiographs identified erosions in only 78 patients (156 body locations). Thus, in this study population, MR imaging had superior sensitivity to bone destruction, suggesting that use of the portable MR system is extremely promising in the assessment of patients with inflammatory arthropathies. To our knowledge, this is the largest series of patients showing the increased sensitivity of MR over radiographic imaging in the detection of erosions. Analysis of intra- and interobserver reliability indicated that there were acceptable agreement (i.e., moderate) values for these parameters, especially considering that the readers were reliable in 84% and 79% of the interpretations, respectively. (Note: Although the kappa values were in the middle range in terms of reliability, it is important to consider the

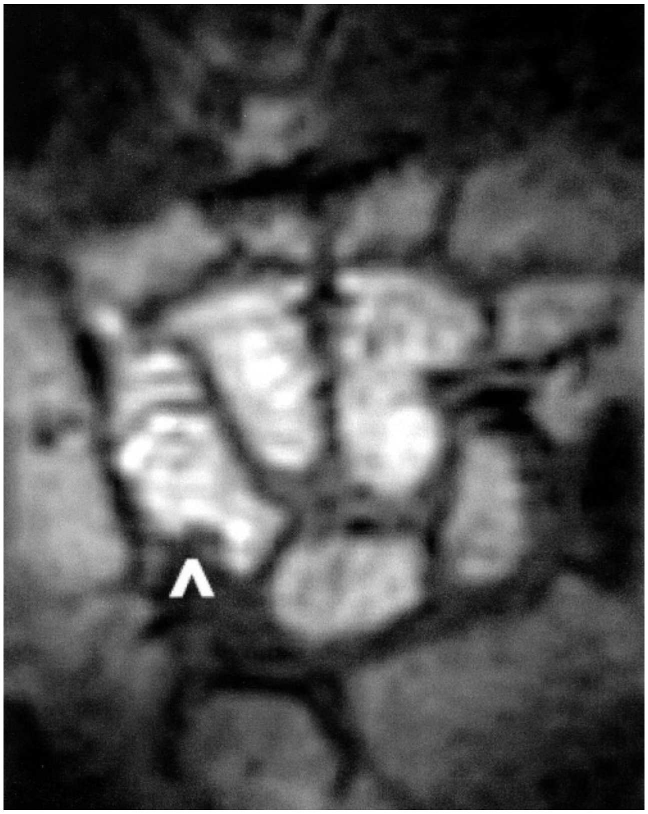
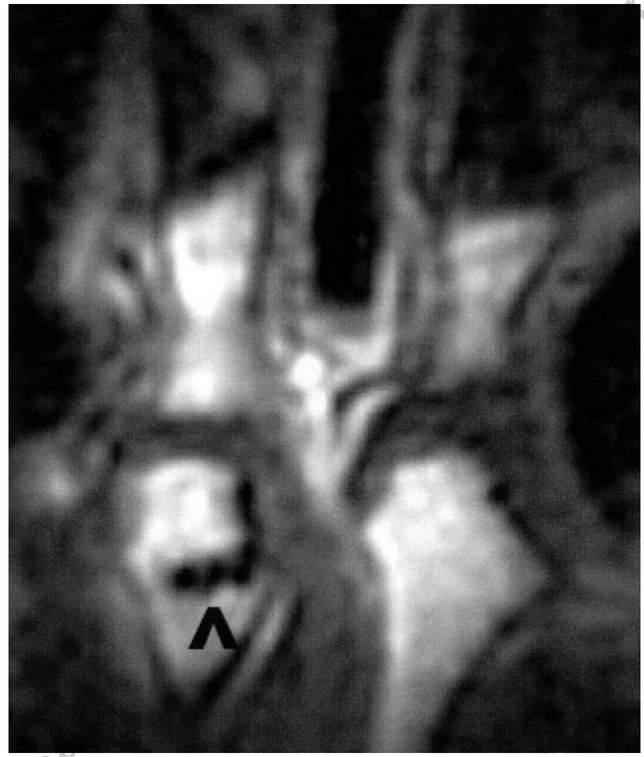


Figure 3. Triquetral "scoop" erosion. A focal region of low signal is seen adjacent to the proximal cortex of the triquetrum in the wrist (arrowhead). This shows the typical gray signal intensity and "scooped out" appearance of the most common type of erosion seen in RA.

A



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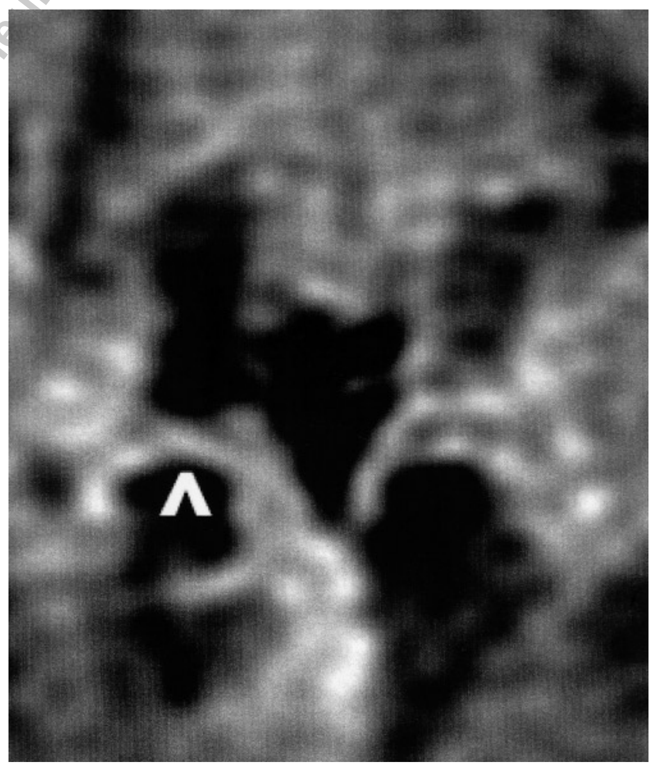
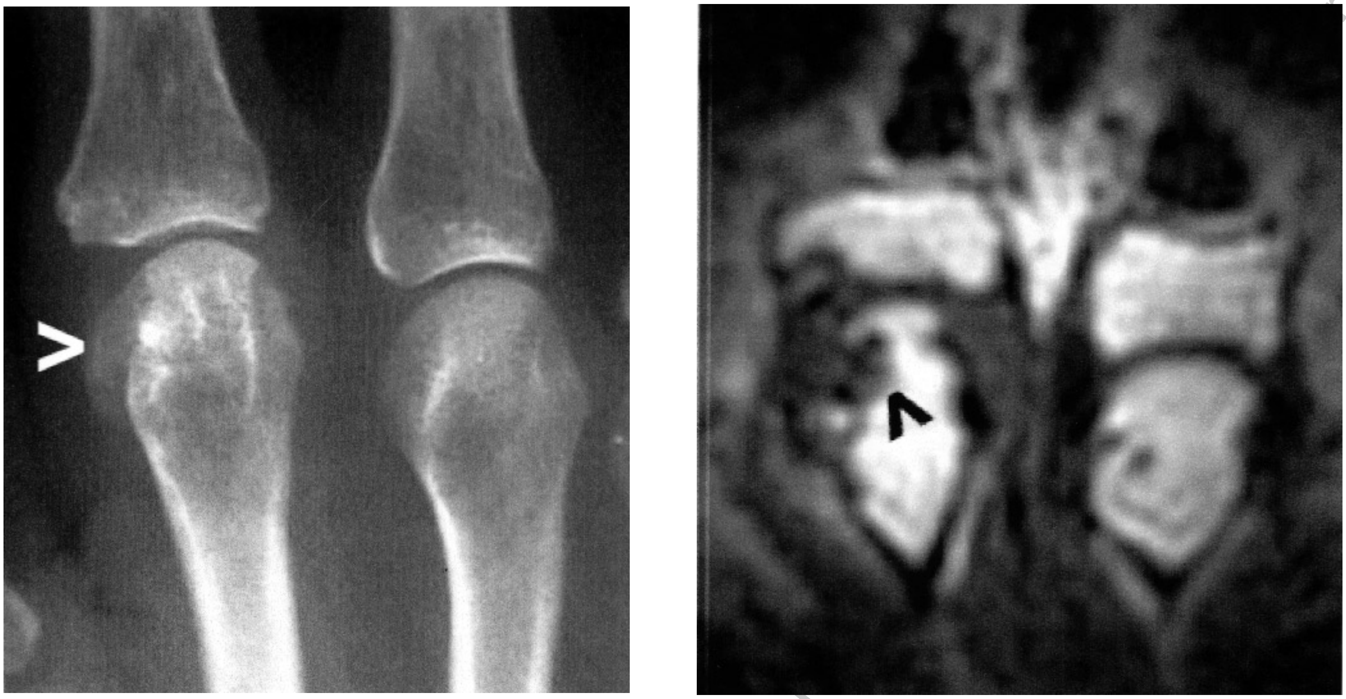


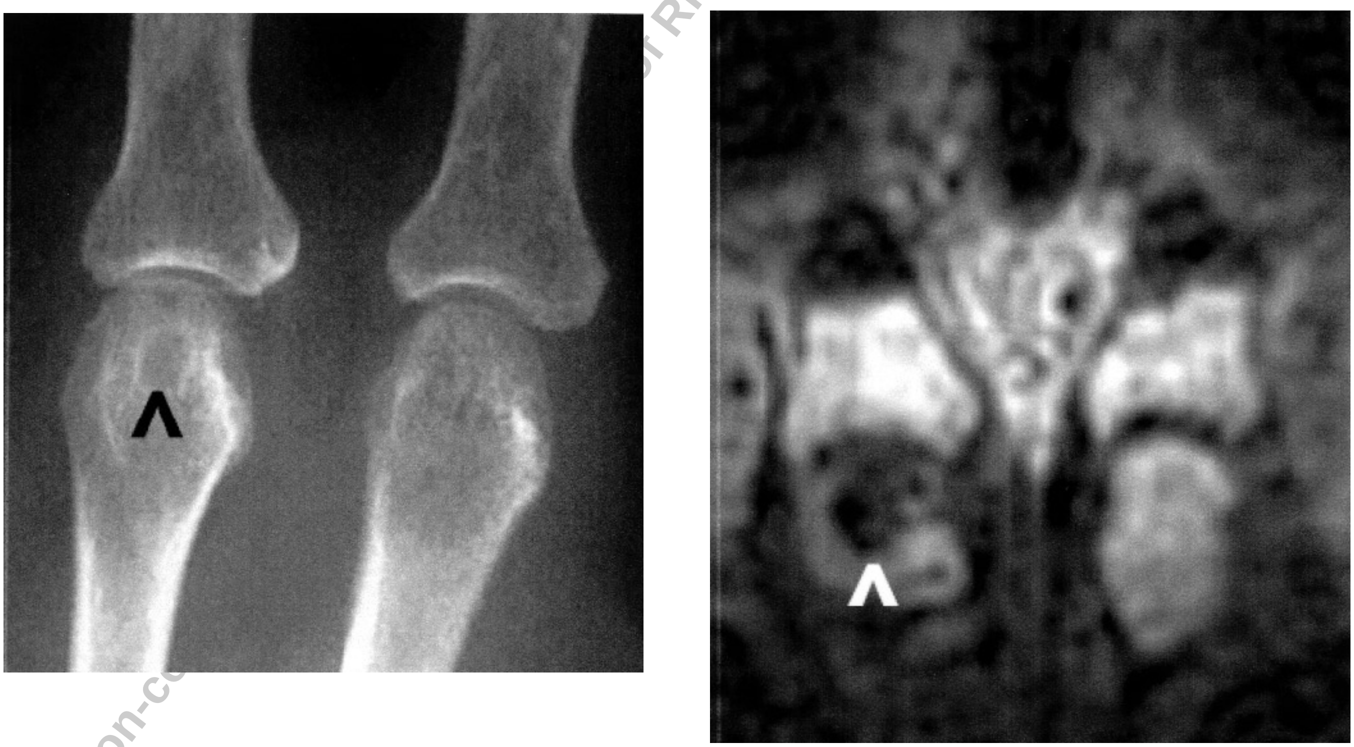
C

Figure 4. Third metacarpal "tunnel" erosion. A. Plain radiograph does not reveal definite evidence of a large erosion. B. T1 weighted MR image shows an erosion involving the radial aspect of the right 3rd metacarpal head (arrowhead). The depth is much greater than the width. C. Typical high signal intensity is seen within the erosion on the STIR image (arrowhead).



A B

Figure 5. An "overhang" erosion. A. Plain radiograph shows marked irregularity of the radial aspect of this left 2nd metacarpal head, a large erosion (arrowhead). B. T1 weighted MR image shows a large radial-side erosion with overhanging margins in good correlation with the radiographic findings on the radial side of the left 2nd metacarpal head (arrowhead). Multiple other erosions were also seen on the MR image, including the radial side of the 3rd metacarpal head and the proximal phalanges.



A B

Figure 6. A "dot" erosion. A. Plain radiograph reveals a "cyst" within the right 3rd metacarpal head (arrowhead). B. In all such examples in our series these cysts were depicted on MR image as low signal "dots" within the involved bone (arrowhead). This one is large, but they all communicated with the cortex of either the dorsal or ventral aspect of the bone. The "cystic" appearance on radiograph and the "dot" appearance on coronal MR image are due to the location of the erosion.

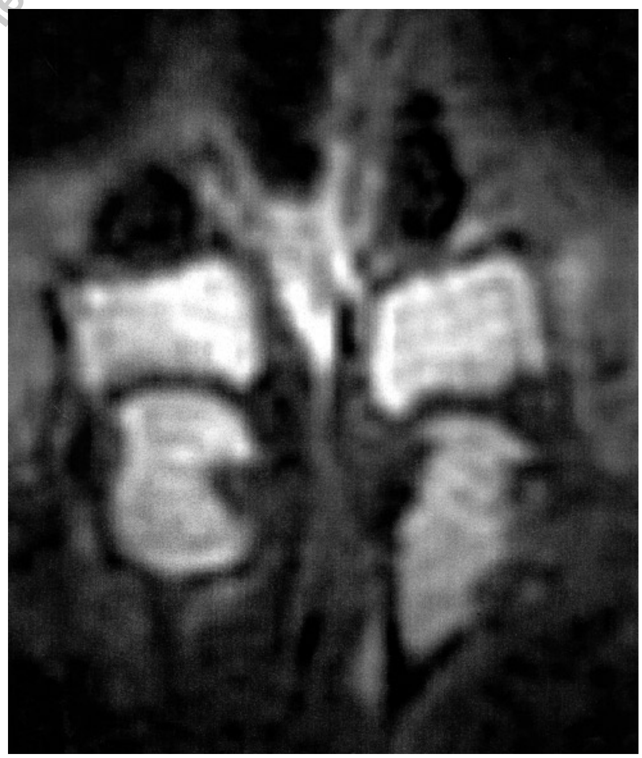
Figure 7. Diffuse carpal erosions. This coronal plane, T1 weighted image through the wrist shows multiple small cortical irregularities involving all bones of the wrist.

statistical test. In both cases, 80% or more of the scores agreed. The statistics fall into the middle range because the kappa coefficient weights the proportion of agreements between observers by the proportion of chance agreement. Since the majority of findings were positive, the proportion of chance agreement is relatively high, driving down the reliability coefficient.)

A recent study by Lindegaard, *et al*[34] used a 0.2 Tesla, extremity MR system (0.2 Tesla, Artoscan, ESAOTE, Genoa, Italy, and General Electric Medical Systems, Milwaukee, WI, USA) for MR imaging and compared the results to radiographs and clinical examinations for detection of inflammation and erosive lesions in wrists and MCP joints in 25 patients with newly diagnosed, untreated RA. The investigators reported that MR imaging identified 57 bones with erosion, while radiographs showed only 6 erosions (i.e., MR imaging to radiograph detection ratio of 9.5:1).

As reported by Lindegaard, *et al*[34], the use of an extremity MR system has several advantages compared with whole-body MR systems. For example, costs are considerably lower, patients can be positioned more comfortably, and claustrophobia, a problem associated with whole-body scanners, is totally avoided[17,34,36,37]. Notably, the portable MR system used in our study is the least expensive (i.e., substantially less expensive than other extremity MR systems) FDA approved, commercially available MR

A



B

Figure 8. Multiple erosions. A. Erosive disease involving both the 2nd and 3rd metacarpal heads on the plain radiograph. B. MR image shows multiple types of erosions in the same individual.

scanner, which should permit it to be used in an extremely cost-effective manner. Performing MR procedures with the portable MR system offers other distinct advantages including reduced start-up costs, more convenient siting and installation, lower maintenance fees, and greater patient comfort and safety (i.e., due to the low field and constrained-fringe field) compared to other extremity MR systems. These unique features allow the portable MR system to be readily utilized in an office or "point-of-care" setting (e.g., rheumatology office or clinic), improving overall patient management and operational efficiency.

Lindegaard, *et al*[34] suggested several possible disadvantages of using an extremity MR system for evaluation of RA. Because the portable MR system used in this investigation is also an "extremity scanner," we are compelled to compare our experiences to these proposed disadvantages. One possible disadvantage of using an extremity[34] or portable MR system is that a smaller field of view must be used compared to a whole-body MR scanner. Therefore, fewer joints may be examined in a given imaging series, requiring longer overall examination time[34]. While this may result in image blurring if patient motion occurs, because extremity and portable MR systems are inherently more comfortable for patients, the length of the MR examination is not considered to be problematic. In support of this contention, only 1% of the patients examined using the portable MR system in this investigation had studies that were technically unacceptable due to motion artifacts.

Lindegaard, *et al*[34] stated that use of the low field extremity MR system is limited by lower spatial resolution. Even though the signal-to-noise ratio (SNR) is directly proportional to field strength, the lower SNR may be addressed on low field MR systems by using additional signal averages or excitations, narrower bandwidths, better radio frequency coil designs, and optimized pulse sequences[36,37]. Further, for musculoskeletal MR imaging, the contrast-to-noise ratio (CNR) is a more clinically relevant parameter because it determines the extent to which adjacent structures can be distinguished from one another and the general conspicuity of pathologic findings[37]. Unlike SNR, the CNR for MR imaging does not decrease substantially with the strength of the static magnetic field[37]. The CNR is primarily dependent on imaging parameters. Thus reduced SNR is not an issue for the portable MR system. This scanner routinely acquires images at a higher isotropic resolution (i.e., in all 3 planes) than is commonly performed even with high field MR systems (typically submillimeter in-plane, but 3 mm through-plane resolution). Thus, rather than being a limitation, higher spatial resolution is a distinct advantage of the portable MR system.

Finally, Lindegaard, *et al*[34] suggested that a possible disadvantage of an extremity MR system is that it does not allow use of a spectral fat-saturation pulse sequence, which provides improved visualization of bone marrow edema, an early sign of bone destruction. Indeed, many of the MR imaging investigations of RA used high field strength MR systems with a fat-suppressed, T2 weighted pulse sequence, which is known to be more sensitive to increased signal intensity as a result of the extended gray scale.

Admittedly, on low field strength MR systems it is difficult to acquire fat-suppressed MR images using frequency-selective techniques because the difference between fat and water spectral peaks is field strength-dependent. Therefore, in our study as well as the one by Lindegaard, *et al*[34], the MR protocol obtained fat-suppressed images using a STIR pulse sequence. However, because the STIR sequence has been reported to be more sensitive than a fat-suppressed, T2 weighted technique for detection of musculoskeletal lesions[40-42], this is not believed to be a disadvantage for the portable MR system, nor should it be an issue for other low field extremity scanners. Indeed, a recent study using a 0.2 Tesla extremity MR system for evaluation of the shoulder used STIR imaging in lieu of a fat-suppressed, T2 weighted sequence, and reported findings for sensitivity and specificity comparable to those indicated for the use of high field and midfield whole-body scanners[43].

Further, spectral fat-suppressed images of the extremities often suffer from non-uniform fat suppression. The failure of spectral fat suppression is most common along the radial and ulnar margins of the hand, where the contour irregularities produce localized field inhomogeneities that can adversely influence the diagnostic quality of the MR examination[17]. This is not an issue for the use of STIR pulse sequences.

Clinical implications. If the presence of erosions on MR imaging prompts clinicians to more aggressively treat patients with RA with newer DMARD, then the cost of MR imaging and accessibility to this diagnostic procedure becomes important. In the clinical setting, office-based portable MR systems may permit treating physicians to make decisions in a more timely manner. Further, these decisions may be more appropriate because of the increased sensitivity of MR imaging for identifying abnormal joint findings associated with RA[17].

As indicated in a recent review by Peterfy[17], it may be possible to follow changes in erosion size using MR imaging, because shrinking erosions can provide direct evidence that the erosive process has stopped. This critical information can provide more timely and convincing evidence of treatment efficacy in contrast to monitoring the failure of new erosions to develop, which is the criterion that the use of radiographs must rely on for evaluating antierosive therapy. Additional studies are warranted to define the use of portable MR systems in a point of care setting.

Limitations. There are several possible limitations of this study. Although the participating radiologists have years of experience interpreting musculoskeletal MR images, the spatial resolution of the images in this study is much higher than that used for "routine" hand and wrist MR examinations. Consequently, we observed many variations in the contour of bone cortices that are not resolved with standard imaging and may mimic erosions. Thus, much of the inter- and intraobserver variability may have been due to the lack of familiarity with the normal cortical contours in the early part of this study, as Reader 1's first interpretations were performed throughout the study, whereas most of Reader 2's interpretations (compared with Reader 1's first interpretations) and all of Reader 1's second interpretations were performed at the end of the study, when both readers were more familiar with the normal high resolution anatomy of the wrist and MCP joints.

Another potential source of error responsible for intra- and interobserver discrepancies was disagreement on the identification of erosions on the plain radiographs. In cases where a question of erosion was raised on radiographs, the radiologist scored the area as either positive or negative before reviewing the MR image. If an erosion was present on the MR examination in the area in question on the radiographs, then the radiographs were called positive, maximizing the sensitivity of the radiographic interpretation.

This study also suffers from the lack of an established "gold standard" for comparing MR imaging to radiographs, as pathologic studies are not available in these patients. Fortunately, extensive clinical experience is available from standard MR imaging, so that the basic appearance of RA erosions on MR is well established and believed to be specific for RA in this patient population[16,17,20-34]. Additionally, there appears to be a low incidence of "false positive" findings for control subjects, as reported by Lindegaard, *et al*[34] and Ejbjerg, *et al*[44].

This study compared MR images obtained using a portable MR system to conventional radiographs in the detection of erosions of the wrists and MCP joints in patients with inflammatory arthritis. The findings in a large group of patients indicated that there was superior sensitivity to bone damage using the portable MR system compared to radiographs, suggesting this MR scanner is extremely promising in the assessment of patients with RA or other erosive arthropathies.

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